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A METHOD OF SUBDIVIDING THE INTERIOR OF A SIMPLY CLOSED RECTIFIABLE CURVE WITH AN APPLICATION TO CAUCHY'S THEOREM

F. B. WILEY AND G. A. BLISS

The Jordan[1] proof of the Cauchy theorem requires that all points of the closed curve C and its interior lie in a region in which the integrand function is continuous and has a continuous derivative. In the Goursat and in the Moore proofs[2] the requirement that the derivative be continuous is avoided, but there are still restrictions on the character of the curve C other than that it be rectifiable. These restrictions are indicated in Moore's statement of the theorem which we quote:

"The definite integral

$$\int_C f(z)\,dz$$

exists and has the value zero, if

(1) the path of the integration C is a simply closed continuous rectifiable curve met by the various lines parallel to the xy-axes in the z-plane $(z=x+iy)$ in a finite number of points and segments of coincidence, and moreover having the property (2);

(2) for every point ζ of C, if a square with sides parallel to the axes converges in any way to the point ζ, the ratio of the total length of the arcs of C lying on the square to the perimeter of the square is ultimately less than a certain constant ρ_ζ which may vary as ζ traverses C;

(3) on the region R, consisting of the curve C and its interior region, the integrand function $f(z)$ is a single valued continuous function of z with a single valued derivative $f'(z)$."

The restrictions of (1) and (2) on the path of integration C, otherwise than that it be closed and rectifiable, have been avoided by Moore at the close of the article to which we have referred, by

[1] Jordan, *Cours d'Analyse*, 2d. ed., vol. 1, (1893), §§196–198.

[2] Goursat, *Cours d'Analyse Mathématique*, vol. 2, (1911), §§286–7. Moore, *Transactions of the American Mathematical Society*, vol. 1, (1900) p. 499.

applying his method of proof to the triangle to which Jordan[3] reduces the problem.

Our purpose in this paper is to accomplish the same result for a simply closed curve by applying a subdivision theorem due to Bliss[4] which takes the place of the Jordon reduction to a triangle.

We start with a simply closed rectifiable curve C which is entirely interior to a region in which the integrand function $f(z)$ is continuous and has at each point a unique derivative. Our method consists in showing in the first place, in §1, that the region enclosed by the curve can always be subdivided into a finite number of regions[4] each of which can be surrounded by a rectangle in which $f(z)$ satisfies the above hypothesis. Then in §2 it is shown that Cauchy's theorem holds for each of these rectangles and consequently (§3) the Cauchy theorem holds for any simply closed rectifiable curve in each rectangle. It readily follows that (§4) the Cauchy theorem holds for our original curve C.

§1. A Method of Subdividing the Interior of a Simply Closed Rectifiable Curve

In this section we show, after stating certain preliminary theorems, first, by means of an auxilliary theorem and then a main theorem, how the interior of a simply closed rectifiable curve C may be subdivided into regions each of which has its maximum diameter less than an arbitrarily assigned constant ϵ; and second, for a curve C lying in a simply connected continuum, that the number of subdivisions necessary to permit each subregion to be surrounded by a rectangle lying wholly in the continuum is finite—a formula for the maximum number being exhibited. It is understood that by a rectifiable curve is meant a continuous curve with length.

We are presupposing the following theorems.[5] Any simply closed rectifiable curve C in an xy-plane divides the plane into two continua, an exterior and a finite interior. Any two interior

[3] *Loc. cit.*

[4] Bliss, *Princeton Colloquium*, Part I, p. 29.

[5] Osgood, *Lehrbuch der Funktionen Theorie*, chapt. V.; Bliss, A Proof of the Fundamental Theorem of Analysis Situs, *Bulletin of the American Mathematical Society*, Vol. 12 (1905-06), p. 336; also Brouwer, Beweis des Jordanschen Kurvensatzes, *Mathematische Annalen*, vol. 69 (1910), p. 169.

points can be joined by a rectifiable curve every point of which is an interior point, and a similar statement holds for exterior points. Any continuous curve joining an interior point and an exterior point must have on it at least one point of the curve C. Every point of C is a limit point of both interior and exterior points.

We define, for the moment, the effective length of a curve to be the length of that part of the curve that lies in no horizontal line.

We state the auxiliary theorem;

If y_1 and y_2 are the maximum and minimum values of y in the interval

$$t' \leqq t \leqq t''$$

for a simply closed rectifiable curve C

$$x = \varphi(t), \quad y = \psi(t) \qquad (t' \leqq t \leqq t'')$$

then there is a segment $p'p''$ of the horizontal line l,

$$y = \tfrac{1}{2}(y_1 + y_2),$$

interior to C except for its end points, which forms with C two simply closed rectifiable curves. If

$$y_1 - y_2 > \epsilon,$$

the segment can be so introduced that each of these curves has an effective length greater than ϵ.

Let p_1 and p_2 be the two points on C at which y is a maximum and a minimum respectively. Select points p'_1 and p'_2 which are interior points of C and so near to p_1 and p_2, respectively, that the former is above the line l and the latter below it. We may join the points p'_1 p'_2 by means of a continuous polygen D having a finite number of sides and consisting entirely of interior points of C.

Any side of D which has an end point in common with the line l may be rotated slightly about its other end point, and in this way it may be brought about that D has only interior points of its sides in the line l, and actually crosses the line where they have a point in common.

The polygon D must intersect l at least once, say at a point p, since one end point of D is above and the other is below the line. There will be a segment $p'p''$ of l containing p such that p' and p'' are on the curve C while every other point of the segment is interior to C. There can be only a finite number of such segments $p'p''$ since D has at most a finite number of intersections with the horizontal line. There must be at least one of them on

which D has an odd number of intersection points, since otherwise both end points of D would be on the same side of the line l.

If $p'p''$ is such a segment, then it forms with C two simply closed rectifiable curves C_1 and C_2 one of which encloses p'_1 and the other p'_2, for after its last intersection with $p'p''$ the polygon D, and hence p'_2, is entirely exterior to the curve C_1.

If $y_1 - y_2$ is greater than ϵ, then the point p'_1 can be chosen so near to p_1 that its vertical distance to the line l is greater than $\epsilon/2$. The altitude of the curve C_1 must then be greater than $\epsilon/2$. The effective length must at least equal twice the altitude. Thus the effective length of C_1 is greater than ϵ. C_2 is handled in like manner.

We now take up the main theorem of this section:

The interior of a simply closed rectifiable curve.

$$x = \varphi(t), \qquad y = \psi(t) \qquad (t' \leqq t \leqq t'')$$

can be divided by a finite number of segments of straight lines into regions each of which has a maximum diameter less than an arbitrarily assigned positive constant ϵ.

If the altitude of any closed curve is greater than ϵ, the effective length of either of its two parts after subdivision by a horizontal line segment, as described in the auxiliary theorem, will be less than $L - \epsilon$ where L is the length of the curve.

If the altitude $y_1 - y_2$ of C is greater than ϵ, then the effective arc of either C_1 or C_2 will be greater in length than ϵ and the effective arc of each will also be less than $L - \epsilon$, where L is the perimeter of C as above.

The curves C_1, C_2 may next be subdivided as in the auxiliary theorem. If the curve C_1 for example, has still an altitude greater than ϵ, the two curves into which it is subdivided will have effective lengths less than $L - 2\epsilon$. By a continuation of this process of simultaneous subdivision the interior of C will be subdivided after n steps into regions bounded by simply closed rectifiable curves whose altitudes are $< \epsilon$ or else whose effective lengths are less than $L - n\epsilon$. If $n \geqq L/\epsilon - 2$ then each subdivision will be in altitude, or else have effective length, $< 2\epsilon$. But in the latter case also its altitude must be less than ϵ.

In a similar manner the regions so formed may be subdivided by vertical segments into others whose breadths are less than ϵ.

If in the above discussion we replace ϵ by $\epsilon/\sqrt{2}$, the theorem follows at once since each sub-region lies in a square of side $\epsilon\sqrt{2}$ and hence has a diameter less than ϵ.

The number of line segments necessary for the subdivision of the region in the interior of C into regions of diameters less than ϵ is not greater than $4^{L\sqrt{2}/\epsilon}$.

To develop this formula we note, by continuing the process indicated in the main theorem, that 2^n-1 line segments give 2^n regions each with altitude less than ϵ or else with an effective arc less than $L-n\epsilon$. By taking n greater than L/ϵ we see that any arc with altitude still greater than ϵ would necessarily have effective length less than zero, which is impossible. This gives $2^{L/\epsilon}$ as a maximum for the number of regions necessary for the subdivision of C into sub-regions with altitudes less than ϵ. In a like manner we show that $2^{L/\epsilon}$ is a maximum for the number of sub-regions into which each of the regions just obtained needs to be divided to insure that the breadth of each will be less than ϵ. It follows that $4^{L/\epsilon}$ is a maximum for the number of sub-regions into which it is necessary to divide the interior of C so that the length and breadth of each region will be less than ϵ, while $4^{L\sqrt{2}/\epsilon}$ is a maximum for the number of sub-regions into which it is necessary to divide the interior of C to insure that the maximum diameter of each region be less than ϵ, and this can be accomplished by drawing not more than $4^{L\sqrt{2}/\epsilon}$ line segments.

The continuation of the subdividing process until the maximum diameter of each region is at most ϵ, where ϵ is taken less than the minimum distance from C to the boundary of a continuum in the interior of which the curve is supposed to lie, insures that each region may be surrounded by a rectangle lying wholly in the continuum and establishes the proof of the corollary we now state.

If our given curve C lies in a simply connected continuum and if ϵ is taken less than the minimum distance from C to the boundary of the continuum, then $4^{L\sqrt{2}/\epsilon}$ is a maximum for the number of line segments necessary to divide the region in the interior of C into sub-regions each of which may be surrounded by a rectangle lying wholly in the continuum.

§2. The Cauchy Theorem for a Rectangle

In the present section we show that the definite integral

$$\int_R f(z)\, dz$$

exists and has the value zero, where R is the border of a rectangle in the interior of, and on which, $f(z)$ is holomorphic.

We take up at once the theorem of this section of the paper, using the method of proof due to Moore.[6]

The definite integral

$$J = \int_R f(z)\, dz$$

exists and has the value zero if the path of integration R is any rectangle, and if in the interior of R and on R itself the integrand function $f(z)$ is a single valued continuous function of z with a single valued derivative $f'(z)$.

We may consider without loss of generality the rectangle R as given with its sides parallel to the xy–axes. Since the path curve R is rectifiable and $f(z)$ is continuous on R the integral J exists.[7] We show by indirect proof that $J = 0$.

Set $|J| = \eta$ and assume $\eta > 0$. By the introduction of two diameters, the rectangle is subdivided into four equal rectangles

$$R_1', R_1'', R_1''', R_1''''.$$

Define J_1' and η' by the equalities

$$J_1' = \int_{R_1'} f(z)\, dz, \qquad |J_1'| = \eta_1',$$

and likewise for J_1'', J_1''', and J_1''''. Then we have

$$J = J_1' + J_1'' + J_1''' + J_1''''$$

and

$$0 < \eta \leqq \eta_1' + \eta_1'' + \eta_1''' + \eta_1''''.$$

Hence at least one of the four η_1's must be at least $\eta/4$. Choose such an η_1 and denote it by η_1 without superscript. Do likewise

[6] *Loc. cit.*

[7] Moore, *loc. cit.*

for the corresponding J_1 and R_1. Then in R_1 we have $\eta_1 > 0$ as in the original rectangle R we had $\eta > 0$.

Thus for every integer ν there is a rectangle R_ν whose longest side is $\gamma/2^\nu$ when γ is the largest side of R. The integral

$$J_\nu = \int_{R_\nu} f(z)\, dz$$

satisfies the inequality.

[1] $$|J_\nu| = \eta_\nu \geqq \eta/4^\nu.$$

This dissection process determines a definite point $z = \zeta$ which lies in every rectangle R_ν, and is either interior to or on R. For every point z of the rectangle R_ν one has the inequality

$$|z - \zeta| \leqq \sqrt{2}\,\gamma\, 2^{-\nu}.$$

We set for points z interior to or on R

$$f(z) = f(\zeta) + (z-\zeta) f'(\zeta) + \Delta(z).$$

By introducing a positive number ϵ subject to later determination, one has interior to or on R_ν

[2] $$|\Delta(z)| \leqq \epsilon |z-\zeta| \leqq \epsilon\gamma\, 2^{-\nu}\sqrt{2}$$

provided that ν is taken sufficiently large, say greater than ν_ϵ.

We now integrate along the rectangle R_ν. This gives

$$J_\nu = \Big[f(\zeta) - \zeta f'(\zeta)\Big] \int_{R_\nu} dz + f'(\zeta) \int_{R_\nu} z dz + \int_{R_\nu} \Delta(z)\, dz$$

which in turn gives

[3] $$J_\nu = \int_{R_\nu} \Delta(z)\, dz$$

in view of the fact that $\int dz$ and $\int z dz$ taken along R_ν are seen without difficulty to vanish.

From [2] and [3] we obtain

$$|J_\nu| = \eta_\nu \leqq \sqrt{2}\,\epsilon\gamma\, 2^{-\nu} \lambda_\nu,$$

where λ_ν is the total length of the rectangle R_ν. Since

$$\lambda_\nu \leqq 4\gamma\, 2^{-\nu},$$

then

$$\eta_\nu \leqq 4\sqrt{2}\,\epsilon\gamma^2\, 4^{-\nu}.$$

This, because of [1], gives

$$\eta \leqq 4\sqrt{2}\,\epsilon\gamma^2.$$

But the positive number ϵ remains at our disposal and, since η is greater than zero, may now be so chosen that

$$4\sqrt{2}\,\epsilon\gamma^2 < \eta.$$

This is in contradiction with the preceding inequality, and completes the proof of the theorem.

§3. The Cauchy Theorem for Any Simply Closed Rectifiable Curve in a Rectangle in Which the Integrand Function Has a Derivative.

In this section we establish the theorem:

The definite integral

$$\int_C f(z)\, dz$$

exists and has the value zero if the path of integration C is any closed rectifiable curve consisting only of interior points of a rectangular region on which the integrand function $f(z)$ is a single valued continuous function of z with a single valued derivative $f'(z)$.

We establish this theorem by setting up a single valued function $F(z)$ which has the derivative $f(z)$, and then showing by means of an auxiliary theorem that for any rectifiable curve C in the rectangle

$$F_1(Z) - F(z_0) = \int_{z_0C}^{Z} f(z)\, dz,$$

from which the proof of the main theorem follows.

The integral

$$\int_C f(z)\, dz$$

exists because the curve C is rectifiable and the function $f(z)$ is continuous on C.[8] We define R (Fig. 1) as a rectangle with its sides parallel to the xy-axes; (a, b) as the lower left-hand vertex of R; z as any point (x, y) of the rectangle; L as the path from (a, b) to (x, y) that is parallel to the axis of reals from (a, b) to (x, b) and then parallel to the axis of imaginaries from (x, b) to (x, y); L' as the path that is parallel to the axis of imaginaries from (a, b) to (x, y) and then parallel to the axis of reals from (a, y) to (x, y); and

$$F(z) = \int_L f(z)\, dz.$$

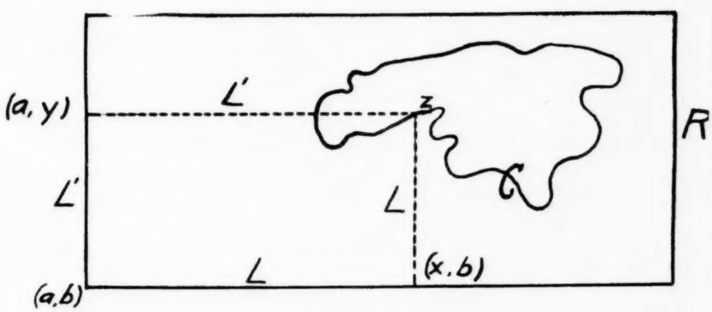


FIG. 1

From the definitions it follows that

$$[4] \qquad F(z) = \int_a^x f(x+ib)\, dx + i \int_b^y f(x+iy)\, dy.$$

In consequence of Cauchy's theorem for a rectangle as proved in §2 this may be written

$$[5] \qquad F(z) = i \int_b^y f(a+iy)\, dy + \int_a^x f(x+iy)\, dx.$$

From [4] we have

$$\frac{1}{i}\frac{\partial F(z)}{\partial y} = f(x+iy) = f(z)$$

[8] Moore, *loc. cit.*

and from [5]

$$\frac{\partial F(z)}{\partial x} = f(x+iy) = f(z).$$

Thus

$$\frac{\partial F(z)}{\partial y} = i\,\frac{\partial F(z)}{\partial x},$$

from which we see that the Cauchy-Riemann differential equations are satisfied and $F(z)$ is monogenic. We conclude that

There exists a function $F(z)$ well defined and single valued in the rectangle R and such that

$$\frac{dF(z)}{dz} = f(z)$$

for every z in R.

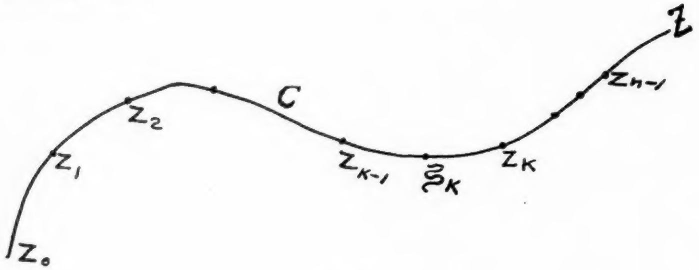


FIG. 2

We next take up a second auxiliary theorem:

If in a neighborhood of a rectifiable curve C the function $f(z)$ is single valued and continuous and the derivative of a single valued continuous function $F(z)$, then

$$\int_{z_0C}^{Z} f(z)\,dz = F(Z) - F(z_0),$$

where z_0 and Z are the end points of C (Fig. 2).

For use in this theorem we shall understand that

$$\int_{z_0C}^{Z} f(z)\,dz = \mathop{\mathrm{L}}_{\Delta z=0} \sum_{k=1}^{n} f(\zeta_k)\,\Delta z_k,$$

where z_k $(k = 1 \ldots\ldots, n)$ are ordered points on the arc z_0Z of the curve C, z_n being the same as Z, and ζ_k is any point on the arc $z_{k-1}z_k$, while Δz_k is the chord $z_k - z_{k-1}$.

Let K be a curve

$$x = \varphi(t),\ y = \psi(t) \qquad (t_0 \leqq t \leqq T)$$

for which φ and ψ are not only continuous but except at a finite number of points have continuous derivatives. We now establish our theorem by showing first that along a curve K, for example a polygon, which satisfies these continuity conditions, we have

$$\int_{z_0K}^{Z} f(z)\,dz = F(Z) - F(z_0).$$

We then complete the proof by using Jordan's[9] method of proving that the value of the integral along a polygon K inscribed in the arc C approaches the value of the integral along C, where C is any rectifiable curve, from which we are able to show that

$$\int_{z_0C}^{Z} f(z)\,dz = F(Z) - F(z_0).$$

Taking up the first step in the proof we may write $\zeta = \xi + i\eta$ and for one of the intervals along the curve K we may write

$$[6] \qquad f(\zeta_k)\,\Delta z_k = [u(\xi_k, \eta_k) + iv(\xi_k, \eta_k)]\,(\Delta x_k + i\Delta y_k) =$$
$$u(\xi_k, \eta_k)\,\Delta x_k - v(\xi_k, \eta_k)\,\Delta y_k + iv(\xi_k, \eta_k)\,\Delta x_k + iu(\xi_k, \eta_k)\,\Delta y_k.$$

If now we let τ_k be the value of t for which, by the mean value theorem,

$$\Delta x_k = \varphi'(\tau_k)\,\Delta t_k,$$

where Δt_k is the t-interval corresponding to Δx_k, and let (ξ_k, η_k) be the point on K corresponding to τ_k, then we have for the first term of [6]

$$u(\xi_k, \eta_k)\,\Delta x_k = u[\varphi(\tau_k), \psi(\tau_k)]\,\varphi'(\tau_k)\,\Delta t_k.$$

We now sum these expressions for $k = 1$ to n and then pass to the limit as $\Delta\tau$ approaches zero. This gives

$$\operatorname*{L}_{\Delta\tau=0} \sum_{k=1}^{n} u(\xi_k, \eta_k)\,\Delta x_k = \int_{t_0}^{T} u[\varphi(t), \psi(t)]\,\varphi'(t)\,dt.$$

[9] *Loc. cit.*

After treating the three remaining terms of [6] in the same manner, we have

$$[7] \quad \int_{z_0 K}^{Z} f(z)\, dz = \int_{t_0}^{T} [u\varphi'(t) - v\psi'(t)]\, dt + i \int_{t_0}^{T} [u\psi'(t) + v\varphi'(t)]\, dt,$$

where u and v are functions of $\varphi(t)$ and $\psi(t)$ as expressed above. Furthermore we know that

$$\int_{t_0}^{T} [u\varphi'(t) - v\psi'(t)]\, dt = \Phi(T) - \Phi(t_0)$$

and

$$\int^{T} [u\psi'(t) + v\varphi'(t)]\, dt = \Psi(T) - \Psi(t_0)$$

provided that $\Phi(t)$ and $\Psi(t)$ are anti-derivates of the functions

$$u\varphi'(t) - v\psi'(t), \qquad u\psi'(t) + v\varphi'(t),$$

respectively. But if we write

$$F(z) = U(x, y) + i\, V(x, y),$$

we have, according to the proof of the first theorem of this section,

$$\frac{\partial U}{\partial x} = u, \quad \frac{\partial V}{\partial x} = v, \quad \frac{\partial U}{\partial y} = -v, \quad \frac{\partial V}{\partial y} = u,$$

and hence

$$\int_{t_0}^{T} [u\varphi'(t) - v\psi'(t)]\, dt = U(X, Y) - U(x_0, y_0),$$

$$\int_{t_0}^{T} [v\varphi'(t) + u\psi'(t)]\, dt = V(XY) - V(x_0, y_0).$$

From this result and [7] it follows that

$$\int_{z_0 K}^{Z} f(z)\, dz = F(Z) - F(z_0).$$

Our next step is to show that the integral along C, where C is any rectifiable curve, is equal to the integral along K, where K is a suitably chosen polygon inscribed in C, also joining z_0 and Z. We accomplish this by showing that the inequality

$$[8] \qquad \left| \int_K f(z)\,dz - \sum_{k=0}^{n-1} f(z_k)\,\Delta z_k \right| < \epsilon,$$

where the sum is now taken along the curve C, can always be made to hold for an arbitrarily chosen ϵ by taking Δz_k sufficiently small.

The polygon K now is formed by joining in order, the points of subdivision z_k $(k = 0, \ldots, n)$ of the arc z_0Z of C (Fig. 3). On account of continuity and therefore the uniform continuity of $\varphi(t)$, $\psi(t)$ on the interval $t_0 \leqq t \leqq T$, Δz can be taken small enough to insure that all of the points of K are in that neighbor-

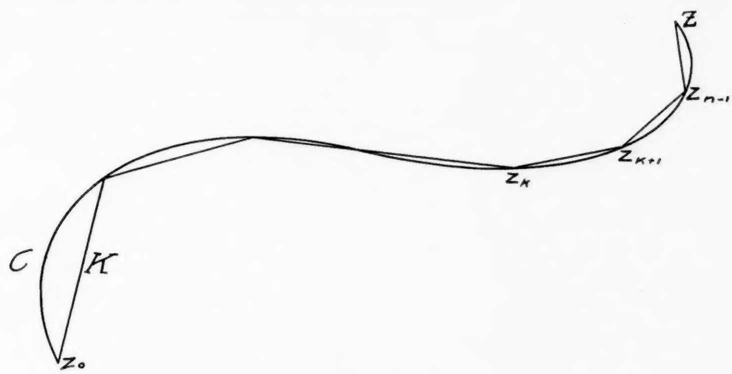


FIG. 3

hood of C where $f(z)$ and $F(z)$ are single valued as indicated in the hypothesis of our theorem. In the expression [8] the term

$$f(z_k)\ (z_{k+1} - z_k)$$

corresponding to the element z_kz_{k+1} is replaced in the integral along K by the expression

$$\mathop{\mathrm{L}}_{n_k=\infty} \sum_{i=0}^{n_k-1} f(z_{i,k})\ (z_{i+1,k} - z_{i,k})$$

where $z_{i,k}$ are points of subdivision of the line z_kz_{k+1}. Since

$$z_{k+1} - z_k = \sum_i (z_{i+1,k} - z_{i,k}),$$

the difference between the integral from z_k to z_{k+1}, taken along the side of the polygon K, and the term mentioned above will be

$$\underset{n_k=\infty}{\mathrm{L}} \sum_i f(z_{i,k})\,(z_{i+1,k} - z_{i,k}) - f(z_k)\,(z_{k+1} - z_k).$$

$$= \underset{n_k=\infty}{\mathrm{L}} \sum_i [f(z_{i,k}) - f(z_k)]\,(z_{i+1,k} - z_{i,k}).$$

On account of the uniform continuity of $f(z)$ in the neighborhood of C specified in the theorem, there exists, for a given ϵ, a δ such that

$$|\, f(z') - f(z'') \,| < \epsilon/L$$

whenever z', z'' are in the neighborhood of C specified in the theorem and

$$|\, z' - z'' \,| < \delta.$$

The constant L is the length of the curve. Take

$$|\, \Delta z_k \,| < \delta \qquad (k = 0, \ldots, n-1).$$

Then

$$|\, z_{i,k} - z_k \,| < |\, z_{k+1} - z_k \,| < \delta.$$

and hence

$$|\, f(z_{i,k}) - f(z_k) \,| < \frac{\epsilon}{L}.$$

It follows that

$$\left| \sum_i \left\{ f(z_{i,k}) - f(z_k) \right\} (z_{i+1,k} - z_{i,k}) \right| \leqq \frac{\epsilon}{L} \sum_i \left| z_{i+1,k} - z_{i,k} \right|.$$

Summing these inequalities for $k = 0, \ldots, n-1$, and taking the limit as the numbers nk simultaneously approach infinity, we see that inequality [8] follows without difficulty, and we are able to conclude that

$$\int_{z_0 C}^{Z} f(z)\, dz = F(Z) - F(z_0),$$

which establishes our auxiliary theorem.

From these two auxiliary theorems we see that the main theorem stated at the beginning of this section follows at once for a closed curve C when we recall that the function defined in the first of these theorems is single valued.

§4. The Cauchy Theorem for a Curve C in any Simply Connected Continuum

In this section we take up the proof of the main theorem of our paper.

Subdivide the region interior to the simply closed rectifiable curve C lying in a simply connected continuum until each subdivision can be surrounded by a rectangle lying wholly in the continuum (see §1). The integral of $f(z)$ taken around the border of each sub-region exists and has the value zero (§3). The integral of $f(z)$ taken around the curve C is equal to the sum of the integrals of $f(z)$ taken around the border of each of the sub-regions in the sense determined by the direction the integral is taken around C. Thus we have the theorem:

The definite integral

$$\int_C f(z)\, dz$$

exists and has the value zero if the path of integration C is a simply closed rectifiable curve lying within a simply connected continuum on which the integrand function $f(z)$ is single valued, continuous, and possesses a single valued derivative.

The University of Chicago, April, 1913.

THE INFLUENCE OF GLACIATION ON AGRICULTURE IN OHIO[1]

Edgar W. Owen

It is a generally accepted view that glaciation has been of very considerable benefit to agriculture, and that one of its effects has been to greatly increase the fertility of the soil. The purpose of the investigation reported here was to determine the real effect of glaciation on agriculture in certain typical districts along the glacial boundary in Ohio. Detailed comparisons were made of the values of farm products in two regions of central Ohio, which were half glaciated and half unglaciated. An area of 468.24 square miles (149.38 unglaciated), centering about Canton, and including Stark county and parts of Carroll, Summit and Tuscarawas counties, and an area of 430.37 square miles (223.39 unglaciated) about Millersburg, consisting of Holmes and parts of Wayne and Coshocton counties, were chosen. These localities (fig. 1) were taken because in them all other conditions than glaciation, influencing agriculture, were constant throughout each section. The parts of these sections north of Canton and Millersburg were glaciated, whereas the land to the south was unglaciated.

In the Canton or Stark county area the most common outcropping rocks belong to the Pottsville and Allegheny formations, with scattered beds of Monongahela, all of which form soils of about equal suitability for cultivation. The climate and topography, with the exception of the changes wrought in the latter by glaciation, are identical throughout the area. Nearness to market, transportation facilities, drainage (except for differences due to glaciation), and all other conditions effecting this problem, are the same for both the glaciated and unglaciated parts.

The same equality of conditions is noted in the Millersburg or Holmes county district. The prevailing outcrops there belong to the Pottsville and Allegheny, with some Waverly rock showing along the stream courses. The topography in this district is

[1] Report rendered in an advanced course in Geography under the direction of Prof. Frank Carney.

somewhat smoother in both unglaciated and glaciated portions than in the Stark county region.

Detailed information was obtained from the State Agricultural Commission concerning amounts, values and acreage of all farm products in 1912, a typical year. This data was compared on a township and acreage basis for both areas chosen, and a number of methods of comparison were employed to avoid erroneous conclusions, the two areas being used as checks on each other. Townships crossed by the glacial boundary were not considered because of the impossibility of getting reliable data for portions of a township.

The first method of comparison was of the number of bushels, tons or pounds produced per acre, of the more common crops in the different townships. The following results were noted:

			(Bu. per A.)					(Tons per A.)
	wheat	*rye*	*oats*	*corn*	*potatoes*	*apples*	*peaches*	*hay*
Canton area								
Glaciated......	9.9	13.2	43.2	39.1	97.0	37.4	32.8	1.25
Unglaciated...	8.8	15.2	34.3	38.2	99.7	14.0	29.7	1.08
Difference.....	1.1	2.0	8.9	0.9	2.7	23.4	3.1	0.17
In favor of....	Gla.	Ung.	Gla.	Gla.	Ung.	Gla.	Gla.	Gla.
Millersburg area.								
Glaciated......	9.0	11.2	33.7	35.4	94.8	70.4	25.0	1.17
Unglaciated...	10.2	7.6	31.5	37.2	72.8	69.4	23.7	1.10
Difference.....	1.2	3.6	2.2	1.8	22.0	1.0	1.3	0.07
In favor of....	Ung.	Gla.	Gla.	Ung.	Gla.	Gla.	Gla.	Gla.

It is seen that there is a great irregularity in these results. Some crops seem to grow better on the glaciated land, while for others the unglaciated is more favorable. For a number of the crops the yield is greater in the unglaciated part of one section and in the glaciated portion of the other, e.g., wheat and corn. Considering the whole area, the glaciated land seems to have a slight advantage in productivity, which however is not at all general or regular. This would seem to indicate that so far as directly enriching the soil goes, the glacier exerted little or no influence.

The second method of comparison was by figuring the total values for all farm products for each township. Here the true effect of the glacier became manifest. Values were regularly much higher throughout the glaciated townships than in the

unglaciated townships and this was true of both sections studied. The average values per acre (considering total areas, whether cultivated or not), were considerably greater in both of the glaciated portions than in the corresponding unglaciated districts. The following were the results obtained:

	Total values	*Total acreage*	*Value of products per acre*
Canton area			
Glaciated	$5,238,780	204,022	$25.6
Unglaciated	$1,727,169	95,613	$18.1
Millersburg area			
Glaciated	$2,621,592	137,237	$19.1
Unglaciated	$2,348,581	142,980	$16.5

It is seen that this result is just opposite to that obtained in comparing amounts per acre, when only the acreage devoted to the crop considered was included.

The explanation of this seeming discrepancy is found in a comparison of the percentages of cultivated land in the different townships. Regularly throughout the glaciated townships the percentages of cultivated land were much greater than in the unglaciated ones. This is evident from the following figures:

	Average per cent of cultivated land per township	*Average per cent of waste land per township*
Canton area		
Glaciated	68.1	3.9
Unglaciated	32.4	5.3
Difference	35.7	
Millersburg area		
Glaciated	65.2	4.8
Unglaciated	46.4	4.1
Difference	18.8	

In the unglaciated townships a much larger proportion of the land was used as pasture or was wooded. The action of the glacier in smoothing the land and rendering more of the country available for cultivation is plainly shown by these results.

The values of live stock were then compared for all the townships. Sheep were raised much more extensively in the unglaciated areas, due to the great extent of land which was unavailable for much but sheep pasturage. The number and value of all other

FIG. 1. LOCATION MAP, BASED ON A MAP ISSUED BY THE DEPARTMENT OF AGRICULTURE, WASHINGTON.

farm animals were much greater in the glaciated townships because of the greater abundance of good feed other than pasturage.

	Average values per township				
	Horses	*Cattle*	*Sheep*	*Wool*	*Hogs*
Canton area					
Glaciated	$81847	$54098	$1434	$522	$9682
Unglaciated	$56606	$34389	$7810	$3346	$6110
Millersburg area					
Glaciated	$72080	$42582	$5183	$2017	$13357
Unglaciated	$51250	$32997	$7452	$3451	$7291

The above facts appear to warrant the following conclusions:

1. The glacier exerted no great influence on soil fertility, as the comparison of crop yields per acre plainly indicated. In the case of certain crops the glaciated land did seem to be slightly more productive, but this was only in a few cases and was by no means a general or regular result.

2. The glacier did however exert a great influence on agriculture by leveling the surface of the land over which it passed. An examination of the topographic maps of the areas studied shows the glaciated region to be much more even than the unglaciated tracts adjoining, as the front of the glacier marks the boundary between the more regular and the less even surfaces. The percentages of cultivated land in the different areas indicate this leveling effect conclusively, a direct economic consequence of which is seen in the greater value of farm products in the glaciated part than in an equal area of unglaciated land. The value of this glacial smoothing depends upon the nature of the surface before glaciation; the effect would naturally be more marked in rough than in smooth country. It is thus seen that while the ice sheet did not materially effect the fertility of the soil in this region, it was of great economic importance in making more of the land available for profitable cultivation.

THE LOCUST GROVE ESKER, OHIO[1]

JAMES D. THOMPSON, JR.

Among the many forms which glacial deposits assume one of the most striking and interesting is the esker. The winding ridges of glacial origin have long been recognized as distinct features; the term "esker" was applied to them by the geologists of Ireland who noted their occurrence in that country in large numbers. The term "asar" is of Swedish origin and was applied to the same formations as found upon the Scandinavian peninsula.

Among the geologists who did pioneer work on the subject of eskers in this country are such men as N. H. Winchell, I. C. Russel, Warren Upham, G. H. Stone, W. B. Crosby, T. C. Chamberlin, and W. M. Davis. Chamberlin and Davis made especially important contributions bearing on the formation of eskers. Mr. D. Hummel[2] of the Geological Survey of Sweden first suggested the theory that eskers had been formed by sub-glacial stream action. After no little controversy this theory has been generally accepted.

Other Ohio Eskers. Leverett in Monograph XLI of the U. S. Geological Survey describes eleven eskers as follows: (1) The Circleville Esker, Pickaway County, p. 429–431; (2) An esker in Fairfield Township, Huron County, p. 597; (3) The Hartland Esker, Huron County, pp. 615–617; (4) The Leesville Esker, Crawford County, p. 542; (5) An esker near Norwalk, Huron County, pp. 587–588; (6) The Pickerington Esker, Fairfield County, pp. 428–429; (7) The Radnor Esker, Delaware and Marion Counties, pp. 540–541; (8) The Richland Esker, Logan County, pp. 489–490; (9) The Richwood Esker, Union County, p. 540; (10) An esker near Springboro, Warren County, pp. 532–533; (11) The Taylor Creek Esker, Hardin County, pp. 538–540.

Scheffel has described a group of eskers south of Dayton,[3] and Morse one at Columbus.[4]

[1] Work done in a course in Geology, under the direction of Prof. Frank Carney.

[2] James Geikie, *The Great Ice Age*, p. 170.

[3] Scheffel, *Ohio Naturalist*, vol. viii, 1908.

[4] W. C. Morse, *Ohio Naturalist*, vol. vii, 1907, pp. 53–72.

Description. The Locust Grove Esker, approximately three-quarters of a mile in length and oriented S.55°E., is situated about three miles southwest of Newark, Ohio, at Locust Grove on the Baltimore & Ohio Railroad, Shawnee Branch (fig. 1). The esker is in an angle of Dutch Fork, a tributary of the South Fork of the Licking River. On the south it gradually flattens out in the valley bottom, which has been covered over by a layer of silt. A thorough search failed to reveal any continuance of the esker south or southwest of Dutch Fork.

The Locust Grove Esker consists of two main segments, being interrupted about midway between its termini. This interruption does not appear to be due to any post-glacial stream action, as the esker is evidently in its original form. Near its northern end, the esker has been cut away by a small stream flowing into Dutch Fork. The portion of the ridge lying north of this point is low and comparatively flat, and is some 40 or 50 feet in breadth.

The esker is nearly straight, and its main part has an average height of 24 feet 11 inches, the extremes being 30 feet 6 inches, and 21 feet 8 inches. Its width varies from 80 to 100 feet. The southern half of the esker is quite regular in form and gradually flattens out upon the valley floor several hundred feet from the stream. The surface of the northern half of the ridge is irregular. Two very short distributaries and several kettle holes may be noted here also. This part of the esker rests upon a deposit of glacial till which has been deeply cut by Dutch Fork, disclosing a fresh bank some 40 feet high. The entire hill to the top of the esker is 60 feet above water level.

The upper part of this till section disclosed by the river consists of yellow gravelly clay containing a few large stones. In the lower part of this yellow till are masses of bluish clayey material which is evidently partly metamorphosed. The upper till section here exposed is severely weathered and rusted to a considerable depth. At other points close at hand the stream has exposed quantities of the bluish clay which is usually overlain by a few feet of silt. No very fresh unweathered till was observed in the immediate vicinity of the esker.

Although no complete section of the Locust Grove Esker is exposed, the surface and other slight exposures indicate stream deposited drift.

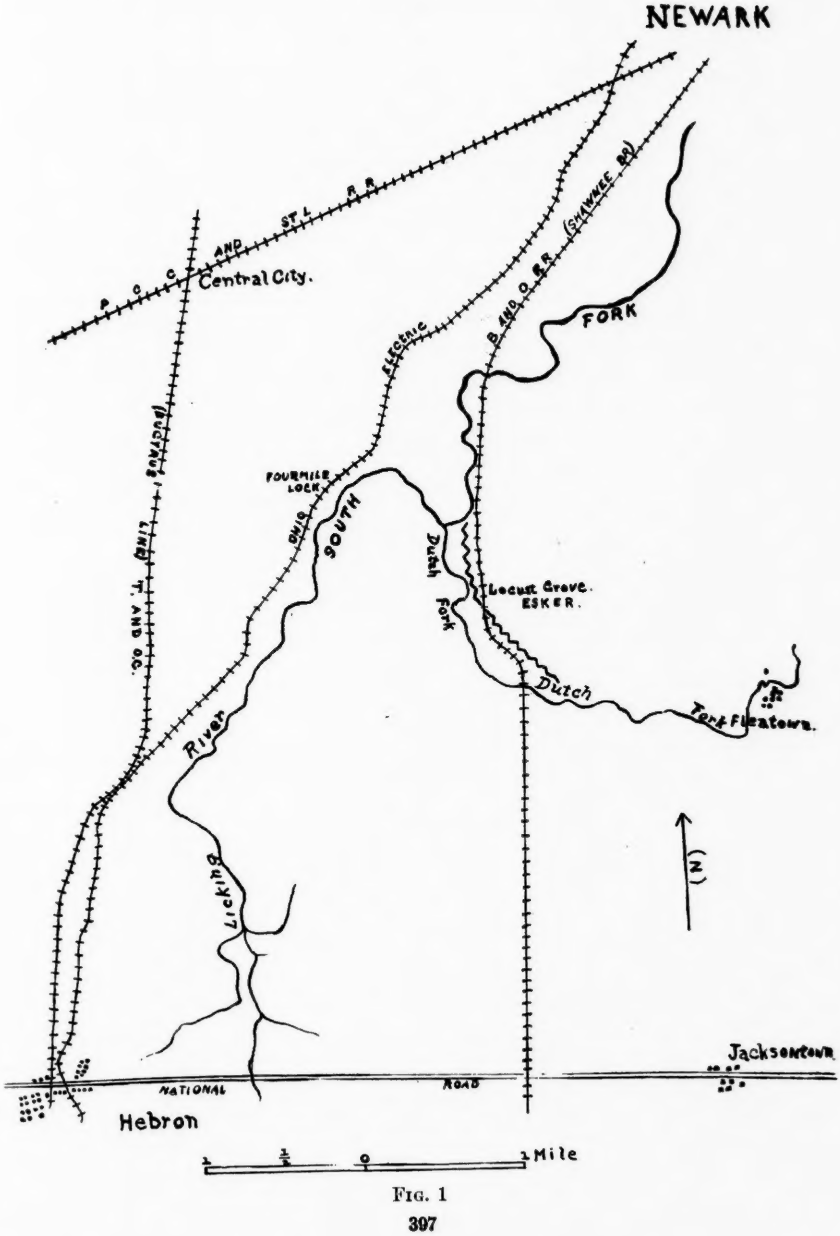

NEWARK
P. C. C. AND ST. L. R. R.
Central City.
T. AND O.C. (LINE) Bucyrus
ELECTRIC
OHIO
FOURMILE LOCK
B. AND O. R.R. (SHAWNEE BR.)
FORK
SOUTH
Dutch Fork
Locust Grove. ESKER.
Dutch
Fork
Fleatown.
River
Licking
(N)
Jacksontown
NATIONAL
ROAD
Hebron
1 ½ 0 1 Mile

FIG. 1

Origin. There are two ice invasions with one of which the formation of the Locust Grove Esker must be associated: the Illinoian and the Wisconsin. Drift from both these invasions occupies the region south of Newark.[5] We find that the drift of the Wisconsin invasion extends out over the Illinoian drift in this area, and in some places we find them intermingled.

The drift of any particular region is always characterised by local material. In some cases it is difficult to determine to which of these two invasions certain drift materials should be attributed. Sometimes we note the Illinoian drift overlain by early Wisconsin drift, which in turn is overlain by later Wisconsin drift.

The till of the Wisconsin invasion is generally composed of yellow gravelly clay, somewhat loose in texture. The later Wisconsin drift is practically unweathered, while that of the earlier periods is more or less weathered and rusted to some depth.

The till of the Illinoian period is also a gravelly clay. Usually where the till is 20 feet or less in thickness, it is yellow in color and shows evidences of prolonged weathering; where thicker than 20 feet the lower part of the Illinoian is generally a bluish gravelly clay, more or less metamorphosed.

Conclusion. The Locust Grove Esker is evidently not of Illinoian origin. The till immediately beneath it, however, is too highly weathered to be of the late Wisconsin period, and we may be justified in concluding that the esker is of early Wisconsin origin.

[5] Leverett, *Monograph XLI*, U. S. Geol. Survey, 1902, pl. XIII.

NOTES ON AGELACRINIDAE AND LEPADOCYSTINAE, WITH DESCRIPTIONS OF THRESHERODISCUS AND BROCKOCYSTIS

Aug. F. Foerste

CONTENTS

1. Introduction

In preparing the descriptions of *Thresherodiscus* and *Brockocystis* it was found necessary to make a study of related genera and species. This led to an accumulation of notes, a part of which are presented in the following pages. Among these are notes on the floor plates and covering plates of the ambulacral rays and on the substomial chamber or cavity in various *Agelacrinidae.* While it has long beeen recognized that a new generic term should be proposed for the Ordovician species usually referred to *Agelacrinus* or *Lepidodiscus,* no new name is offered here since Dr. Bassler is engaged at present on a study of this group.

The writer is under special obligations to Dr. E. O. Hovey, of the American Museum of Natural History, in New York City; to Prof. Stuart Weller, at Chicago University; to Prof. A. D. Hole, at Earlham College in Richmond, Indiana; and to Prof. S. R. Williams, of Miami University, at Oxford, Ohio, for the loan of *Agelacrinidae* from the Museums of which they have charge. Specimens have been borrowed also from the collection of Dr. G. M. Austin, of Wilmington, Ohio.

It has been found possible to determine the systematic position of the fragmentary specimens described by Billings under the terms *Apiocystites tecumseth* and *Apiocystites huronensis,* species whose systematic position hitherto has been in question.

The writer is under obligations also to Dr. R. W. Brock, the

director of the Geological Survey of Canada, under whose auspices he was permitted to make the investigations which led to the discovery of the unique specimens here described under the new generic terms, *Thresherodiscus*, and *Brockocystis*.

2. Character of Surface Used for Support by Ordovician Agelacrinidae

The Ordovician species referred to *Agelacrinus* occur chiefly on *Rafinesquina*. Among 17 specimens of *Agelacrinus cinncinatiensis*, 16 occurred on *Rafinesquina*, and 1 appeared to have been unattached. Among those found on *Rafinesquina*, all were attached to convex surfaces; 13 on the exterior of the pedicel valves, and 3 on the interior surface of brachial valves. Among 26 specimens of *Agelacrinus pileus*, 23 were found on the exterior of the pedicel valves of *Rafinesquina*, 1 appeared to have been unattached, and 2 were attached to bryozoans: one of these bryozoans was *Homotrypa flabellaris*, and the other, *Heterotrypa frondosa*. The types of *Agelacrinus holbrooki*, *Agelacrinus warrenensis*, and *Agelacrinus vetustus* occur on *Rafinesquina*. The type of *Agelacrinus faberi* (plate III, Fig. 4) occurs on the brachial valve of *Hebertella alveata*. The Ordovician *Agelacrini* probably settled on any convenient convex surface on the sea bottom, and the valves of *Rafinesquina* were preferred on account of their comparative smoothness.

3. Orientation of Agelacrinus pileus on Sloping Supports

In the case of the more convex species, such as *Agelacrinus pileus*, with one dextral and four sinistral rays, the orientation of the specimens appears to have been chiefly such as to place the anal interambulacral area on the right side of the sloping surface. For instance, among 24 specimens of *Agelacrinus pileus*, 14 had this anal interambulacral area on the right side of the specimen; in 4, this area was directed diagonally downward toward the right; in 3, it was directly downward and toward the left; in 1, it was directed toward the left; and, in 2, it was directed diagonally upward and toward the left. The direction in which the surface, upon which each individual rested, sloped, was determined in each case by noticing in what direction the specimen of *Agelacrinus*

had sagged (plate II, Fig. 1) on the death of the animal. Toward the upper part of the sloping surface, the peripheral area was broadly expanded by the tension. Toward the lower part of this sloping surface, the peripheral area of the *Agelacrinus* was distinctly narrower, sometimes conspicuously so. The predominance of the cases in which the anal interambulacral area was directed toward the right side of the sloping surface suggests that the orientation preferred by the animal was one which would lift the anal area to about the same level as the oral aperture. The anal area is rarely directed either straight down or straight up the sloping surface, the latter being an extremely uncommon position. The location of the anal interambulacral area on the right side of the sloping support, is shown also by *Agelacrinus holbrooki* (plate I, Fig. 1 D).

The reason for this orientation in the case of *Agelacrinus pileus* and *Agelacrinus holbrooki*, for the present, can be only a subject of speculation. It is noted, however, that among 22 specimens of *Agelacrinus pileus*, 5 rested upon valves of *Rafinesquina* having their anterior margins directed toward the lower part of the slope; 7 rested upon valves with their right anterior or left anterior outlines directed downward; and 6 rested upon valves with the lateral outlines directed downward, so that 18 out of 22 specimens rested upon valves having some part of the convex outline of the valve directed downward. This is the position which specimens of *Rafinesquina* should assume if occurring singly on sea bottoms swept by mild currents. In only 2, among the 22 specimens, was the anterior margin at the top of the sloping surface; and in the remaining 2 this margin faced diagonally upward. Here, again, the slope of the valves of *Rafinesquina* was determined by the direction in which the theca of the *Agelacrinus* had sagged, on the death of the animal.

If, now, it be assumed that the valves of *Rafinesquina* sloped toward the direction of the prevailing currents, some part of the convex outline facing the current, then the thecae of the *Agelacrini*, resting upon the same, usually would be oriented in such a manner as to prevent the excreta, escaping from the anus, from passing across the oral part, or across any considerable part of the area crossed by the ambulacral rays.

It is probable, however, that the orientation of the animal was determined much more by the requirements for food, than by any

efforts to escape contamination by excreta. In this case it is noted that the predominating position of the animal is such as to bring the proximal parts of the left (No. 2) and right (No. 4) rays, and the connecting peristomial slit, into parallism with the direction of the prevailing currents, as determined from the slope of the *Rafinesquina* upon which the animal rested. By the peristomial slit is meant the slit formed by the peristomial plates, which extends from the median line of the left ray to the median line of the right ray (or from plate Z to plate Y in Figure 5B, on plate I). In this orientation, the proximal part of the right ray is directed up the slope. This position of the animal probably accounts for the direction of curvature of the rays in *Agelacrinus pileus*.

4. Curvature of Ambulacral Rays

Some of the early forms of *Agelacrinus*, such as *Agelacrinus billingsi*, Chapman, from the Trenton, and *Agelacrinus bohemicus*, Barrande, from Etage D, have the rays sharp and quite straight, abutting against or tapering to a broad peripheral margin of larger and smaller plates. In another Trenton form *Agelacrinus dicksoni*, Billings, all the rays are strongly curved in a contrasolar direction. This may be regarded as the primitive condition among species with curved rays. The primitive contrasolar curvature of the rays is indicated even by those Ordovician species in which the right ray is strongly curved in a solar direction distally, since, at the proximal end, this ray begins with a contrasolar curvature. This contrasolar curvature of the proximal part of the right (4) ray is well shown by both *Agelacrinus pileus* (plate II, Figs. 1, 2) and *Agelacrinus cincinnatiensis*, and probably was shown also by other Ordovician species of which this part of the theca, at present, is unknown.

The curvature of the rays, whether in a solar or contrasolar direction, was due to the extensionof the distal part of the rays in the effort to secure more food. This extension could not proceed beyond the inner part of the peripheral ring since this was formed by quite large plates, probably held together fairly rigidly. The extension of the rays, of necessity, therefore, took place along the inner margin of this ring. What caused it to start in a *contrasolar* direction is unknown, but the fact is evident.

The development of species with strongly curved rays from those

with moderate curvature is suggested by the ontogeny of *Agelacrinus cincinnatiensis.* In this species, individuals less than 9 mm. in diameter usually have moderately curved rays with the distal part not parallel to the peripheral ring. Specimens 10 mm. in diameter have a small part of the distal extremity parallel to the ring. In successively larger specimens, a larger and larger part of the distal extremity becomes parallel to the peripheral ring, until in mature specimens, this feature becomes conspicuous. Similar derivation of curved rays from comparatively straight rays have been shown in the ontogeny of *Agelacrinites hamiltonensis* and *Agelacrinites buttsi*, by Clarke, in New Agelacrinites, plate 10, Figs. 6, 7, 8, and 9, in 1901.

5. Cause of Reversal of Curvature of Right Posterior Ray

The cause of the reversal of curvature from contrasolar to solar, of the right posterior(No. 5) ray is unknown. Any attempt to solve the problem must, for the present, again be a subject merely of speculation. Possibly this reversal of curvature is connected with the orientation of the specimen. Even in the living state, the position of the animal on a slanting surface would tend to increase the tension along the upper part of the margin and just within the adjacent part of the peripheral ring. If, at the same time, the anus were dragged slightly downward and toward the left, the proximal part of the right ray (No. 4) being directed up the supporting slope, then the greatest tension would be on the upper, right hand side of the inner curve of the peripheral ring, possibly sufficiently below the distal part of the right posterior ray (No. 5), in young specimens, to loosen the contact between this part of the peripheral ring and the immediately adjacent part of the posterior or anal interambulacral area, and thus to admit of the curvature of the right posterior ray in a solar, rather than a contrasolar direction.

In the case of *Agelacrinus cincinnatiensis,* such a drag of the anus downward and toward the left is suggested by the presence usually of several small plates along the upper margin of the anal pyramid, the proximal part of right ray (No. 4) being directed upward. In one specimen of *Agelacrinus cincinnatiensis,* No. 13266-1-b, belonging to the American Museum of Natural History, these small plates are specially numerous along the upper

right hand side of the anal pyramid, and similar features are presented by the specimen of *Agelacrinus holbrooki* which was figured by Clarke (*New Agelacrinites*, p. 189, Fig. 2, 1901; see also plate I, Fig. 1C, of this BULLETIN), in which the small plates also are specially numerous along the upper right hand margin of the anal pyramid, if the specimen be oriented so as to direct the proximal part of the right ray (No. 4) toward the top.

In specimens of *Agelacrinus cincinnatiensis* in which the supplementary small plates along the upper right hand margin of the anal pyramid are either absent or few, the distal part of the right posterior ray (No. 5) usually is parallel to the peripheral ring and terminates opposite the middle of the anal pyramid. In specimens in which the supplementary small plates are numerous along the upper right hand margin of the pyramid, for example, in specimen No. 13266-1-b, cited above, the tip of the right posterior ray curves distinctly, at the very extremity, away from the peripheral ring, toward the anal pyramid. In typical *Agelacrinus holbrooki*, also with numerous supplementary plates along the upper right hand margin of the pyramid, the tip of the right posterior ray curves still more strongly and terminates above the level of the anal pyramid (plate I, Fig. 1D), the specimen being oriented, as before, so as to direct the proximal part of the right ray (No. 4) toward the top. In this case, also, it will be noted that a few smaller sized plates occur on the inner or concave sides of the distal parts of some of the other rays of *Agelacrinus holbrooki*, possibly owing to crowding.

In *Agelacrinus pileus*, no supplementary smaller plates were noticed along the margin of the anal pyramid, and no evidence is here suggested of any cause for the reversal of curvature of the right posterior ray, from contrasolar to solar.

6. REVERSAL OF CURVATURE IN STREPTASTER

No cause of the reversal of curvature of the right posterior ray of *Streptaster reversata* (plate IV, Fig. 3), described in this paper, is suggested by any detail of structure noted so far. The two species of this genus, previously described, have all the rays curved in a contrasolar direction.

7. Supporting Surface of Agelacrinus Cincinnatiensis Probably More Horizontal than in A. Pileus

An examination of a number of specimens of *Agelacrinus cincinnatiensis* has failed to bring out as strong a connection between the orientation of the individuals and the direction of the slope upon which these individuals were located, as was noted in the case of *Agelacrinus pileus,* and *Agelacrinus holbrooki. Agelacrinus cincinnatiensis* is a larger and flatter species than *Agelacrinus pileus.* The former frequently attained a diameter of 30 mm., occasionally of 33 or even 35 mm. The latter usually did not exceed 15 mm. in diameter, although specimens 20 mm. in diameter have been noted. The specimens of *Agelacrinus cincinnatiensis,* being of larger size, covered a much larger part of the valves of the *Rafinesquina* upon which they rested, and, therefore, were not likely to find a sufficiently large surface unless the valve was more or less horizontal, and not partly imbedded in the mud on the sea bottom. A moderate amount of sagging of the theca, after death, however, was noted. In these cases, the upper part of the peripheral outline is flattened and extended, while the lower part of this outline is shortened, as in *Agelacrinus pileus,* but to a less marked degree.

8. Solar Curvature in the Devonian Agelacrinites and Lepidodiscus

The preceding remarks are based upon an examination of the Ordovician specimens referred to *Agelacrinus* or *Lepidodiscus.* They do not take into account the Devonian *Agelacrinites hamiltonensis,* with both the right (No. 4) and the right posterior ray (No. 5) solar (plate VI, Fig. 3), or *Lepidodiscus alleganius,* with all the rays solar (plate VI, Fig. 2A). The remarks evidently are based on highly speculative inferences, but they at least suggest that some of the characteristics of various species of *Agelacrinus,* may be produced by the orientation of the animal while resting upon some support, especially while engaged in feeding. It may be assumed that the main business of the animal while in life consisted in feeding.

9. Aboral Surface of Lepidodiscus

The oral part of the specimens being at the center of the exposed part of the theca, that part of the theca of the various *Agelacrinidae* which rested upon some shell or other support may be known as the aboral surface. It is probable that this aboral surface varied considerably in different genera, but nothing is known of it excepting in very few species. Clarke, in *New Agelacrinites*, has figured the aboral surface of two specimens of *Lepidodiscus alleganius*. From these specimens it is evident that this *Lepidodiscus* was derived from some more or less globular or oval ancestor covered by imbricating scaly plates which overlapped in a direction from the base toward the upper or oral end. There is no indication of the animal having become attached to a support even temporarily. (Plate VI, Fig. 2B.)

10. Mobile Marginal Part of Peripheral Ring

In all of the Ordovician species referred to *Agelacrinus* or *Lepidodiscus*, however, the animal evidently was capable of attaching itself to various objects for support, although this attachment was not permanent, and occasional specimens are found unattached. The main means of attachment evidently was the margin of the peripheral ring, since the latter always is composed of small plates, closely adjusted to the varying curvature of the underlying support. These small marginal plates are merely the protective covering of the underlying soft fleshy margin of the individual, the close application of which to the underlying *Rafinesquina* or other support permitted the attachment. The slight elevation of the central part of the aboral surface evidently caused the latter to act like an ordinary sucker.

The ready mobility of the marginal part of the peripheral ring is suggested not only by the close application of the latter to the underlying support, but also by the sagging of the specimen, on death and probably also, to a certain extent, during the life of the animal. To this sagging frequent reference has been made in the preceding lines. The fact that some specimens are found unattached also suggests that, when attachment again was desired, the animal was able again to apply this margin of the peripheral ring to the varying curvature of the underlying object sufficiently

closely to secure support. It is inconceivable that this close application of the margin of the peripheral ring could be accomplished if the latter were underlaid by imbricating scales. Therefore, imbricating scales are believed to have been absent at least from that part of the aboral surface which underlaid the margin of this ring.

11. Rigid Inner Band of Peripheral Ring

In agreement with the ready mobility of the marginal part of the peripheral ring, this part is covered with small imbricating plates arranged in diagonal rows. These increase in size toward the inner part of the peripheral ring, forming an inner band of strong plates, usually elongated transversely, or at least so imbricated as to expose only the wide upper margins of the plates. This inner band of large plates rarely has suffered deformation, suggesting that here the plates were held together more or less rigidly. In fact, while the interambulacral surfaces frequently are found sagged below the level of the inner margin of this peripheral band, after the death of the animal, and while even the distal parts of the rays not infrequently give evidence of sagging (see, for instance, Fig. 1, on plate II), the inner band of the peripheral ring usually retains its form. It remains undisturbed even in specimens in which almost all the interambulacral and ambulacral plates are disarranged. The surfaces of these plates of the inner band of the peripheral ring usually are closely applied to each other, forming a rigid circle of plates.

12. Vertical Ridges on Plates of Inner Band of Peripheral Ring

In a specimen of *Agelacrinus* belonging to the American Museum of Natural History, forming No. 13266-1-r of that collection (plate I, Fig. 6E), the under side of the upper or oral face of the theca is exposed. The species is assumed to be *Agelacrinus pileus* on account of the strong convexity of the theca, and its comparatively small diameter: 20 mm. This specimen suggests that not only all of the smaller plates belonging to the marginal part of the peripheral ring, but also the lower margins of the outer two rows of the inner band of much stronger plates, could be brought close

to the underlying surface. The plates belonging to the two outer rows of the inner part of the peripheral band are characterized by the presence of three short ridges. These ridges are found near the basal margins of the plates. In length they vary from four-fifths of a millimeter to less than half a millimeter; and they are equally spaced, the three occupying a width of four-fifths to one millimeter. In direction they vary from approximately vertical to moderately radiating in an upward direction. They fill in the spaces between the adjacent plates belonging to the next inner circle of large plates forming the inner band. They may be merely space fillers, assisting in holding these plates of the inner band rigid, but they may also be points of attachment for muscles. They do not fit into grooves on the distal faces of the adjoining plates of the inner band. These ridges were noted by Meek, presumably in a specimen of *Agelacrinus faberi*, identified by Meek as *Agelacrinus cincinnatiensis*, found by L. B. Case in the upper part of the Richmond group, at Richmond, Indiana. This specimen seemed to have grown on a valve of *Byssonychia*, and exposed the under surface of the oral face of the theca. Regarding this specimen Meek stated: "The disc plates near the outer margin show, on their inner surfaces, little parallel ridges, directed inward, and apparently fitting into corresponding furrows in the lapping edges of the contiguous pieces." I doubt the presence of this corresponding furrows but have not seen the specimen. On specimen 13266-1-s, (plate I, Fig. 6D), belonging to the American Museum of Natural History, there are two thecae of *Agelacrinus pileus*. Of these, one is considerably dismembered and exposes the inner surface of two of the plates belonging to the inner band of the peripheral ring. Here, again, short vertical ridges, 0.4 mm. in length, project from the lower margin of the plate. On one of these plates the vertical ridges occupy a total width of 1 mm.; on the other, of 1.3 mm. They evidently never fitted into grooves in the next inner set of plates.

13. Central Part of Aboral Surface

No definite information has been secured regarding the central part of the aboral surface of the theca, within the space limited by the peripheral ring. Possibly the under side of the oral face of the theca of *Agelacrinus pileus*, figured by Miller and Faber, No.

8825 of the Faber Collection, in Walker Museum, at Chicago University, preserves traces of thin plates belonging to the aboral surface, but I have interpreted these plates as displaced floor plates of the ambulacral rays. Specimens of *Agelacrinus cincinnatiensis,* in which a few of the plates of the oral side of the theca are missing, are not uncommon. On etching away, with caustic potash, the clay filling between this oral face of the theca and the surface of the *Rafinesquina* upon which it rested, no trace of aboral plates were discovered. The finest transverse lines, on the radiating striae of the *Rafinesquina,* however, were preserved. While this evidence is only negative, it may be assumed that in those forms which assumed the sessile habit, the original plates on the aboral surface became obsolete, a fleshy surface, unprotected beneath, being much better adapted for attachment to an underlying surface.

14. Interambulacral Plates

In all of the Ordovician species referred to *Agelacrinus* or *Lepidodiscus,* the interambulacral plates are scale-like and more or less imbricating, overlapping each other in a proximal direction. The degree of overlapping of some of the plates may be small but nevertheless is distinct. It is always greater toward the peripheral band. Even in *Agelacrinus holbrooki* (plate IV, Fig. 1), which Clarke describes as showing mosaic plates in the interradii, while squamose and imbricating at the margin (*New Agelacrinites,* 1901, p. 189), the interambulacral plates overlap proximally at quite acute angles although not for long distances. This is best seen where the plates are more or less loosened but not displaced.

The plates are arranged more or less in rows crossing each other diagonally. This diagonal arrangement continues into the adjacent rows of plates belonging to the peripheral ring.

In view of the theory that the *Agelacrinidae* represent derivatives from a Cystidean ancestry, the imbricating squamose form of plates can scarcely be considered as primitive. The plates of Cystideans are polygonal and form a mosaic, and it is from a polygonal, mosaic stock of plates that those of the *Agelacrinidae* may be supposed to have originated.

The change to imbricating plates probably was due to the assuming of the sessile habit, together with the enormous shortening of the theca in a vertical direction. This caused the distal edge

of one plate to collapse within the proximal edge of the adjoining plate, especially along the margin of the sessile theca, at the peripheral ring. Even in the interambulacral areas, the overlapping is always greater toward the peripheral ring than toward the mouth, as already stated. The imbrication probably began at the peripheral ring, and then progressed proximally to areas nearer and nearer to the mouth.

In that case such species as the Devonian *Agelacrinites hamiltonensis* may be regarded as merely forms in which the imbrication had not proceeded far from the margin of the thecal disc.

In *Streptaster,* the interambulacral plates are small, polygonal in outline, and form a mosaic. In *Streptaster vorticellatus,* these plates are well known near the distal end of one of the interambulacral areas, where they are about half a millimeter in diameter, and form an irregular mosaic of polygonal plates. In *Streptaster reversatus* (plate IV, Fig. 3), the polygonal plates in the area between the left and left posterior rays are even less than half a millimeter in diameter, but in the posterior or anal interambulacral area, where the mosaic of plates consists of an irregular mixture of large and small plates, some of the larger plates attain a diameter of almost 1 mm. In all species of *Streptaster,* the plates forming the inner band of the peripheral ring are strongly imbricating.

In *Hemicystites* the interambulacral plates are squamose and imbricating. In the closely related *Cystaster,* they are rounded or polygonal, and form a mosaic, although the individual plates are of minute size, averaging one-fourth of a millimeter in diameter.

In *Thresherodiscus* (plate III, Fig. 3), the larger interambulacral plates all are squamose and imbricating. The smaller plates, along the lateral margins of the rays, also overlap in a proximal direction, but in a less evident manner.

Theoretically, the earlier forms of *Agelacrinidae* should show less imbrication among the interambulacral plates than the later forms. As a matter of fact, this is not verified by the specimens found so far. Both the imbricating and the mosaic type of interambulacral plates occur in the Trenton, and the oldest species known at present have imbricating interambulacral plates. However, none of these Trenton forms can be regarded as very primitive.

15. Trimerous Origin of Ambulacral System

The ambulacral system of the *Agelacrinidae* evidently is of trimerous origin, although a pseudo-pentamerism has been superinduced upon the same. This pseudo-pentamerism is indicated by the fact that in all Ordovician species referred to *Agelacrinus* or *Lepidodiscus*, rays 1 and 2 (left posterior and left, respectively) and also rays 4 and 5 (right and right posterior) separate from each other at a greater distance from the center than ray 3 (anterior ray). A far more striking illustration of pseudo-pentamerism among the *Agelacrinidae*, however, is given by the *Thresherodiscus ramosa* (plate III, Fig. 3, and Fig. 1 on page 434). Here the trimerous origin of the rays is so evident that it is necessary to number the rays as in the pseudo-pentamerous species of *Agelacrinus* merely to admit of ready comparison with the latter. In *Thresherodiscus*, the ambulacral system originates at the center in three arms, left, anterior, and right, each of which branches dichotomously at a distance of about 2 mm. from the center of the peristomial area, further branching taking place, also in a dichotomous manner, distally. While it was scarcely necessary to discover this genus in order to demonstrate the trimerous origin of the ambulacral system of the *Agelacrinidae*, it must be admitted that *Thresherodiscus* offers a striking confirmation of this origin.

16. Cover Plates of Ambulacral Rays

The cover plates of the *Agelacrinidae* usually are well preserved. In *Agelacrinus pileus* (plate II, Figs. 1, 2), there are two series of cover plates, one on each side of the median line of the ray. In by far the greater number of specimens the proximal side of each cover plate is elongated into an acute spinous tooth which projects across the median line of the ray and interlocks with the opposing cover plate (plate I, Fig. 5A, B, C, also plate II, Fig.1). The latter also has a spinous prolongation on the proximal side, and both cover plates are curved concavely on the distal side of this spine, along the median line of the ray, so as to admit the interlocking. In a few specimens, apparently of the same species, this spinous prolongation is absent or inconspicuous, and the cover plates on opposite sides of the median line of the ray, oppose each other like two series of V's, with their apices alternating (plate II, Fig. 2).

In *Agelacrinus cincinnatiensis*, and in the closely related *Agelacrinus holbrooki* (plate I, Fig. 1C), four series of cover plates are present, two series on each side of the median line of the ray. Of these series, the two outer ones are here called the lateral coverings plates, and the two inner series, intercalated along the median line are called the median or intercalated covering plates. The exposed part of the lateral covering plates are triangular in form, the apices being directed toward the median line; they are of larger size and rest upon the lateral margins of the floor plates. The median or intercalated covering plates are of smaller size and only their tips may be seen, intercalated between the tips of the lateral covering plates, and about equalling the latter in number. Along the ambulacral groove these plates are probably ridged vertically, so as to interlock and also so as to prevent their lateral displacement.

In some of the specimens of *Agelacrinus pileus*, the lateral covering plates differ considerably in size and form, some of them being longer and narrower and approaching the palisade-like effect of *Streptaster*. In these cases the conspicuous elongation is in all cases along the inner or concave curvature of the distal parts of the rays. This projects the median line of the ambulacral ray farther toward the periphery of the theca, and perhaps enlarges the effective feeding area of the animal.

In *Streptaster*, the palisade-like elongation of the covering plates receives its greatest expression. Here (plate I, Fig. 7B, plate IV, Fig. 3), only two series of covering plates are in evidence, one on each side of the median line of the ray. Here, also the tips of the plates interlock by a prolongation of the proximal side of the covering plate into an angulation which fits into a recession located more distally, on the opposing plate. This interlocking may, at first glance, be obscured by the truncated appearance of the tip of the plates, but is shown by all well preserved specimens. If any median or intercalated covering plates were present, the latter must have been very small, and at least have not been identified so far. For the present, *Streptaster* is regarded as related more closely to *Agelacrinus pileus* than to any other known Ordovician species, but it is sufficiently distinguished by the presence of a mosaic of small polygonal plates, quite irregularly arranged, in the interambulacral areas.

In *Thresherodiscus ramosa* the median or intercalated cover-

ing plates are at least as numerous as the lateral covering plates, in some parts of the specimen apparently exceeding the latter in number (plate I, Fig. 8). It is the median covering plates which, in this species, interlock along the median line of the rays, since the lateral covering plates do not reach this line.

It may be noted that even in *Agelacrinus cincinnatiensis* a third series of still smaller plates may be intercalated on each side of the median line, occasionally, producing a very serrate appearance along this line.

In *Cystaster granulatus* each ray has about eleven pairs of covering plates. As in *Agelacrinus pileus,* the spinous prolongation of each covering plate is on the proximal side of the tip. The covering plates are flattened, and the upper parts of the flattened surfaces are inclined distally, or away from the center of the specimen.

17. Peristomial Plates

The peristomial plates of *Thresherodiscus* do not appear to differ conspicuously from the other covering plates. They are not well preserved, but such traces as exist suggest merely a continuation of the series of median and lateral covering plates of the rays also along the peristomial slit. The term peristomial slit is used here for the median line between the covering plates of the ambulacral system along that part which extends across the oral aperture, from the point of bifurcation of rays 1 and 2 (left posterior and left rays) to the point of bifurcation of rays 4 and 5, (right and right posterior rays). In this lack of differentiation of the covering plates in the peristomial region from those on the rays, *Thresherodiscus* resembles the more primitive conditions in the *Cystidea.*

The peristomial plates of *Agelacrinus pileus* (plate I, Fig. 5B, also plate II, Figs. 1, 2) are highly differentiated from those of the rays. In all specimens there is a right anterior (R) and left anterior (L) peristomial plate. These are rhomboid plates, sufficiently extended along their greater diameters to prevent the base of the anterior ray from coming in contact with the base of the right and left rays. Of these, the right anterior rhomboid plate always is taller, so that the first covering plate of the anterior ray is found on the left side of the median line. On the posterior side of the peristomial slit there is a single large plate (P), often

described as quadrangular, but in reality quite irregular in form. Rays 1 and 2 (left posterior and left rays) are separated by a long narrow plate (Z), equally common to both. If this plate not be taken into account, then the first covering plate of the left ray (No. 2) is found on the anterior side of the median line, and the first covering plate of the left posterior ray (No. 1) is found on the posterior or contrasolar side of the median line of this ray. In a similar manner, there is a long narrow plate separating rays 4 and 5 (Y). If this plate not be taken into account, the first covering plate on the right ray is found on the anterior side of the median line of this ray, and the first covering plate of the right posterior ray is found on the posterior or solar side of the median line of this ray.

There is a tendency toward differentiation in form of the first covering plate of the right posterior ray, as defined above. This differentiation is connected with the form of the posterior peristomial plate, and consists in a slight elevation of the basal margin of the covering plate, corresponding to a much more marked raising of the lower right-hand margin of the posterior peristomial plate (P). Usually the first covering plate of the right posterior ray (No. 5) fits snugly against the upper part of the right hand margin of the posterior peristomial plate, often having a convex outline where adjoining the latter, but posteriorly these two plates do not fit as closely to the anterior outline of the immediately adjacent interambulacral plate (X). This suggests the possibility of the exit of some duct at the angle between these three plates (P, X, and 5). No aperture actually penetrating a plate has been noted.

In *Agelacrinus cincinnatiensis*, there is either less constancy in the form and arrangement of the peristomial plates or the peristomial areas of the specimens at hand are not infrequently more or less distorted, and the plates more or less broken. The original of Figure 7, on plate 6, of the *Twenty-fourth Annual Report of the New York State Museum of Natural History*, is by no means as distinctly defined a specimen as the drawing suggests. Many of the details, including those of the peristomial plates, unquestionably were transferred from other specimens, the identity of which is unknown. The plates of the interambulacral areas, with the exception of those on the right side of the specimen, are less numerous than figured. The peristomial plates, and some of the

adjacent plates, are badly weathered. As far as may be determined from all the specimens at hand, the peristomial plates of *Agelacrinus cincinnatiensis* agree with those of *Agelacrinus pileus* in the presence of a rhomboid left anterior plate, a rhomboid right anterior plate, and an irregular, so-called quadrangular, posterior plate; along the lower part of the right hand margin of the latter the border is raised, and at the angle at which the posterior plate is joined by the first lateral covering plate of the right posterior ray and by the adjacent interambulacral plate, there may have been the opening of some duct. However, the long, narrow plates, which in *Agelacrinus pileus* are intermediate between rays 1 and 2, and between rays 4 and 5, have not been identified, and the first covering plate on the contrasolar side of the left posterior ray, in *Agelacrinus cincinnatiensis*, frequently is long and narrow, and parallel to the adjacent oblique left margin of the posterior peristomial plate, instead of resembling the immediately following lateral covering plates of the same ray, as in *Agelacrinus pileus*.

The peristomial area of *Streptaster* is unknown. Judging from the close similarity of the covering plates in some of the specimens referred to *Agelacrinus pileus* to those of *Streptaster* it is suspected that, when the peristomial plates of *Streptaster* are known these also will be found similar to those of *Agelacrinus pileus*.

In *Cystaster granulatus*, the various peristomial plates recognized in *Agelacrinus pileus* (R, L, R, Y, Z, in Fig. 5B, on plate I) may be identified. The two anterior peristomial plates are strongly V-shaped. The posterior peristomial plate also is strongly grooved along the median line, as though it originally consisted of two distinct plates.

18. Floor Plates of Devonian and Carboniferous Agelacrinidae

The plates beneath the ambulacral grooves are known as the floor plates. These floor plates have been known hitherto from only a few species among the *Agelacrinidae*.

In *Haplocystites rhenana*, Roemer, from the lower Devonian of the Rhine, there was only a single row of these floor plates. The species has been refigured by Jaekel (*Stammesgeschichte der Pelmatozoen*, 1899, plate III, Fig. 3), and, according to Clarke, is so closely related to the American *Echinodiscus* or *Lepidodiscus*, that eventually the name *Haplocystites* may displace one of these terms.

The floor plates of *Agelacrinites beecheri* (plate I, Fig. 2). from the lower Carbonic (Olean conglomerate) of Warren, Pennsylvania, are figured by Clarke (*New Agelacrinites*, 1901, p. 195, Fig. 6) as also arranged in a single row, the plates overlapping each other distally, as seen from below.

19. Floor Plates of Ordovician Species Referred to Agelacrinus

Meek, in describing *Agelacrinities cincinnatiensis* (*Ohio Paleontology*, vol. i, p. 55, in 1873) refers to a specimen, a little more than an inch in diameter, found by L. B. Case at Richmond, Indiana, in the upper part of the Richmond group. Judging from the horizon, this specimen may have belonged to *Agelacrinus faberi*, which was described from the same locality and horizon. Regarding this specimen Meek stated: "The inner side of each arm or ray is here seen to be composed of a single series of quadrangular pieces that are not imbricating."

Miller and Faber, in describing the lower surface of the upper side of the theca of a species of *Agelacrinus*, identified as *Agelacrinus pileus* (*Journal of Cincinnati Society of Natural History*, vol. xv, p. 85, plate I, Fig. 10, in 1892; see also plate I, Fig. 5A and plate II, Fig. 4 in this Bulletin), made the following statements, to which are added, in brackets, such explanatory terms as are deemed necessary for a ready understanding of the descriptions given.

> The under side of the rays, as seen from below, consist of a row of plates on each side of the furrow (the covering plates), which interlock at the bottom of the furrow (as seen from below), and are, therefore, without reference to abutting (interambulacral) imbricating plates, pentagonal instead of quadrangular, as Meek described them. (Meek described the floor plates as quadrangular, while Miller and Faber had the covering plates in mind when they described the latter as pentagonal.) They (the bases of the covering plates) extend beyond the margin of the (interambulacral) imbricating plates into the visceral cavity (for a distance equal to) half the depth of the ambulacral furrows (as seen from below), and are separated from each other, in their extensions laterally into the visceral cavity, so as to present a strongly serrated edge, as shown in the illustration (loc. cit., plate I, Fig. 10; see also plate I. Fig. 5A of this Bulletin). The furrows (as seen from below) are covered with thin nonimbricating plates (floor plates), that do not cover the serrated edges above described. Part of the covering (consisting of the floor plates) is preserved in our specimen as shown in the illustration, on two rays (anterior and left rays), but the plates are so small and the

sutures so indistinct, that they could not be shown, except in a greatly magnified view. (It is evident that Miller and Faber regarded the floor of the ambulacral groove as made of a mosaic of numerous minute plates, instead of a single row of large plates, as is, more likely, the fact.) The coverings of the rays are united near the center of the fossil by a subpentagonal rim.

The specimen described by Miller and Faber forms No. 8825 of the Faber Collection, in Walker Museum, at Chicago University. It was found near the top of the hills, at Cincinnati, Ohio, probably in the Corryville member of the Maysville. It is evident that Miller and Faber did not recognize in this specimen the presence of a single row of floor plates.

In the figured specimen, however, the transverse sutures between the floor plates can be distinguished under favorable illumination (plate I, Fig. 5A). As seen from below, the floor is evenly convex in a transverse direction, three floor plates occurring in a length of 2 mm. along the proximal extremity of the anterior ray, and two floor plates, within almost the same length, along the proximal extremity of the left ray. In this specimen, figured by Miller and Faber, the floor plates appear to have a width of about 1.5 mm. and apparently permit the basal extensions of the covering plates, which produce the serrated appearance described by Miller and Faber, to project beyond their margins. I have seen other specimens of *Agelacrinus pileus*, however, in which the floor plates were thicker, and in which they appeared to underlie the entire width occupied by the covering plates, including their basal extensions, so that further investigation on this point is desirable.

In the American Museum of Natural History there is a small *Agelacrinus* (plate II, Fig. 3), numbered 13266-1-x, and obtained at Cincinnati, Ohio. It is only 12 mm. in diameter and evidently is a young specimen. It is assumed to be a young specimen, and is remarkable in showing the under surface of the upper face of the theca with remarkable clearness. In this specimen the floor plates are distinctly defined. They evidently form a single row, are much wider than long and give no evidence of the projection of the basal extension of the covering plates beyond the lateral margins of the floor plates.

Similar features are shown also by *Agelacrinus austini,* from the upper part of the Whitewater member of the Richmond, on Dutch creek, northwest of Wilmington, Ohio. Plate VI, Fig. 1B.

The presence of floor plates is readily verified among Ordovician species referred to *Agelacrinus* and *Lepidodiscus*, provided that the overlying cover plates are carefully removed. They are seen also frequently among the displaced plates of specimens which had more or less disintegrated before being covered by the sea sediment.

In the Geological Museum of Ohio State University, there is a specimen of *Agelacrinus cincinnatiensis*, showing a series of three floor plates in a single row (plate I, Fig. 6C). In this case it is evident that the median part of each plate, as seen from above, was depressed into a wide groove, while a narrow groove extended lengthwise along the border, on each side of the wide median groove. The wide median groove evidently formed part of the ambulacral furrow, while the narrow lateral grooves had some connection with the fulcra of the lateral covering plates, by means of which the latter were opened and closed over the ambulacral furrow.

In the type of *Agelacrinus faberi*, forming No. 8821 in the Faber Collection in Walker Museum, at Chicago University, possibly identical with the species from which Meek described the presence of floor plates, a few floor plates were identified (plate I, Fig. 3C), and plate II, Fig. 4), among the mixture of plates there presented. Three of these floor plates occurred in a single row. Little could be learned from them beyond the fact that these plates are widely grooved along the top, as though the plates were almost evenly concave. They evidently overlapped a little in a proximal direction, as seen from above. The narrow lateral grooves, one on each side of the broad median groove, could not be identified. They may have been present formerly, but the floor plates are badly weathered.

In the type of *Agelacrinus holbrooki*, forming No. 1004, in the James Collection, in Walker Museum, at Chicago University, a series of five floor plates belonging to the left ray (No. 2) are preserved (plate I, fig 1E). Of these, the three floor plates which belong to that part of the ray which is parallel to the peripheral ring, show a comparatively narrow median ambulacral groove, and unusually strong lateral grooves which have some connection with the articulation of the lateral covering plates. In the case of two other plates belonging to the same series, but located nearer the proximal end of the ray, the median, ambulacral groove was much

wider, and there was no indication of lateral grooves. The basal extensions of several of the lateral covering plates, however, were in evidence, and apparently extended beyond the lateral margins of the floor plates. However, since all the floor plates are badly weathered, further evidence is needed on this point. While the basal extensions of the lateral covering plates undoubtedly pass beneath the margins of the adjacent interambulacral plates, it is very likely that these extensions are enclosed, from beneath, by the floor plates, the total width of which probably was greater than suggested by the specimen described by Miller and Faber.

20. Floor Plates of Streptaster

In a specimen of *Streptaster*, found in the upper part of the Whitewater member of the Richmond, about three miles west of Dayton, and regarded as a normal specimen of *Streptaster septembrachiatus*, Miller and Dyer, the most striking feature is the extreme narrowness and considerable height of the ambulacral rays, and the tall, narrow lateral covering plates (plate I, Fig. 7B; also plate IV, Fig. 2) looking like an uninterrupted series of more or less vertical palisades. The enclosed ambulacral cavity is high, but evidently very narrow. The upper ends of the lateral covering plates are blunt, as seen from above. The bases of the covering plates on opposite sides of the rays practically must be in contact with each other. This is seen readily on viewing the rays from beneath.

All the rays are contrasolar. The lateral covering plates rest upon the floor plates—two lateral covering plates on each floor plate, one covering plate on each side of the floor plate. The widest floor plate is barely 1 mm. in width, and this leaves very little space for the ambulacral groove. All five of the ambulacral rays are exposed on the lower surface of the oral face of the theca, and, from this point of view, in all five rays, the floor of the ray consists of a single longitudinal row of floor plates (plate I, Figs. 7A, B), thinning and overlapping in a distal direction, forming angles of about 30 degrees with the former flat base of the theca. It is evident that if the floor plates could be seen from above, the proximal end of one would be found overlapping the distal end of the next, as in all other *Agelacrinidae* in which the floor plates are known. The upper, proximal side of the floor

plate is flattened in a direction parallel to the base of the theca, and this flattened surface supports the lateral covering plates, as already mentioned.

Such traces of the interambulacral plates as remain are seen only from below and are not clearly defined. They, no doubt, were small and polygonal, forming an irregular mosaic as in other species of *Streptaster*.

21. Floor Plates of Thresherodiscus

In *Thresherodiscus ramosa*, the floor plates also occur in a single row (plate I, Fig. 8; also plate III, Fig. 3). The median third of each plate is occupied by a comparatively shallow ambulacral groove. The lateral thirds of the plates are comparatively flat. These lateral parts probably were grooved longitudinally for the articulation of the lateral covering plates, but at present they are too weathered to verify the former presence of the lateral grooves with certainty. The floor plates overlap each other in a proximal direction, when viewed from above.

Toward the tips of the branches of the ambulacral rays, the floor plates so closely resemble the ordinary interambulacral thecal plates that it seems certain that the floor plates of *Thresherodiscus* are to be regarded merely as specialized thecal plates. Some of the rays appear to intrude even upon the upturned margins of the adjacent plates belonging to the inner band of the peripheral ring. In other words, the ambulacral rays are regarded as epithecal.

From the preceding observations it seems probable that the floor plates of all typical *Agelacrinidae* will be found to be arranged in single rows, and to overlap each other proximally, when viewed from above. This proximal overlapping suggests that the floor plates may be modified thecal plates belonging to the upper face of the theca. This would make the floor plates of the *Agelacrinidae* epithecal, the food grooves extending over the thecal plates themselves, without intermediate flooring. In this respect they are similar to the *Diploporita* among the *Cystidea*, from which they differ in other important particulars.

22. Basal Extensions of Lateral Covering Plates of the Ambulacral Rays

The specimen of *Agelacrinus pileus* described by Miller and Faber exposes in a remarkably clear manner the basal extensions of the lateral covering plates of the ambulacral rays (plate I, Figs. 5A, B, C, D; also plate II, Fig. 4). These extensions project laterally from the bases of the covering plates, where they rest upon the floor plates, toward and beneath the adjacent interambulacral plates. They are best exposed along the anterior, right, and right posterior rays, where they are seen for almost the entire length of the ray, and on both sides of the ray, but some of the basal extensions are seen also in case of the left and left posterior rays. Along that part of the base of each covering plate which serves as its fulcrum, there are two striations (plate I, Fig. 5C), which extend in a direction parallel with the ray, and a moderate distance apart. These striations seem to fit against the inner margin of the narrow lateral groove which is seen on the upper side of the floor plates in certain species. From these bases, of the covering plates, the short basal extensions project outward and downward at rather a strong angle with the major part of the covering plate. The basal extensions are wider on the convex side of the rays, and narrower on the concave side, where there is less room. On the convex side of the rays the basal extensions have a length of about 0.5 mm., and narrow from a width of two-thirds of a millimeter, parallel to the length of the ray, to a width of two-fifths of a millimeter at the truncated tip of the extension. On the concave side of the ray, the basal extensions are much narrower, and terminate more acutely; here they have a length of about 0.4 mm. At the angle of junction of the rays, where also the room is restricted, even the basal extensions on the convex side of the rays are narrow and acute. Apparently two lateral plates occur on each side of each floor plate, in the case of the few floor plates preserved.

In some specimens of *Agelacrinus cincinnatiensis*, the basal extensions of the lateral covering plates are very well exposed. They are shown by specimen 1008-c (plate I, Fig. 6B), in the James Collection, at Chicago University, and also are seen along both sides of the left ray, and on parts of the anterior and left posterior rays of specimen No. 13266-1-c, belonging to the Ameri-

can Museum of Natural History. In the latter specimen numerous basal extensions are present. Here it is noted that the exposed ovate part of the covering plate forms about half the length of the plate. Where it adjoins the margin of the adjacent ambulacral plate, the covering plate is bent downward distinctly but not to any great extent, and then resumes the same curvature as the exposed part of the plate. Immediately beyond the point where the covering plate passes beneath the adjacent interambulacral plate, the covering plate begins to narrow rapidly, and then the sides become approximately parallel, forming the basal extension, which only slightly exceeds one-fourth the total length of the plate. At the interambulacral angles, where there is little room, these basal extensions proceed from the distal side of the covering plates and are directed diagonally (plate I, Fig. 6A) toward the median parts of the interambulacral area.

In *Agelacrinus holbrooki,* No. 1004 of the James Collection in the Walker Museum of Chicago University, several of the basal extensions of the covering plates of one of the rays are sufficiently preserved to indicate that the downward flexure of the covering plates, at their contact with the adjacent parts of the interambulacral plates, takes place at about half the length of the covering plates, and from this point the covering plates narrow rapidly, the terminal fourth forming that part of the basal extension which has approximately parallel sides. The basal extensions seen on part of the anterior ray are very narrow (plate I, Fig. 1E), while those on the left ray (plate I, Fig. 1F, are more like those of *Agelacrinus cincinnatiensis.* These differences may be only local differences along the length of the ray, or may be due to weathering in case of the very narrow basal extensions. Here, again, two covering plates appear to occur on each side of the floor plates.

In *Thresherodiscus* (plate I, Fig. 8), two lateral covering plates also occur on each side of the floor plates. There is no evidence whatever of basal extensions of these coverings plates. In fact, there is no room for the same. In this respect, the covering plates of *Thresherodiscus* resemble those of the *Cystidea.*

Basal extensions of the covering plates are unknown also in *Streptaster* (plate I, Fig. 7B). They probably were absent in the Devonian and Carboniferous *Agelacrinidae,* in which the rays are very narrow (plate I, Fig. 2). It is possible that the presence of basal extensions of the lateral covering plates may prove to be

one of the characteristics serving to distinguish the Ordovician species, usually referred to *Agelacrinus* or *Lepidodiscus*, from the typical Devonian species of these genera. The presence of two lateral covering plates on each side of at least all the larger floor plates has not been established as definitely as desirable, but this also may prove to be a characteristic of the unnamed Ordovician genus as compared with the typical Devonian representatives of *Agelacrinus* and *Lepidodiscus*.

23. Anal Pyramid

The anal pyramid of *Agelacrinus cincinnatiensis* is remarkably well preserved by specimen No. 13266-1-h, belonging to the American Museum of Natural History. Here it consists of an exterior set of eight ovate plates, meeting at the center, and glimpses of three additional plates, belonging to the next inner circle. In specimen No. 13266-b, belonging to the same museum, there are also eight plates belonging to the outer circle of the anal pyramid, and more or less evident indications of eight plates belonging to the inner circle, and alternating with the outer circle. The plates of the inner circle probably were narrower than those of the outer circle, corresponding in this respect to the intercalated plates of the ambulacral cover series. The under side of the larger plates, belonging to the outer series of the anal pyramid, was ribbed longitudinally along the median line, so as to prevent displacement laterally, in this respect also corresponding to the lateral covering plates on the ambulacral rays.

In the closely related *Agelacrinus holbrooki* (plate I, Fig. 1C), there was also an outer series of large ovate plates, and an inner, narrower series, alternating with the former, but the number of each was not determined.

In *Agelacrinus pileus* there also is evidence of larger and smaller sized plates in the anal pyramid, but the outline of the pyramid does not appear to form as rigid a circle, and toward the center these plates overlap more in an imbricating manner so that the margins do not resemble as closely the radii of a circle.

In *Agelacrinus austini* (plate VI, Figs. 1A, C) the anal pyramid consists of an outer circle of 6 ovate triangular plates, with probably an equal number of plates forming an inner circle, but usually hidden more or less by the outer circle.

In *Thresherodiscus* it has been impossible to determine whether the anus is located in the bottom of the depression on the right side of the posterior interambulacral area, or at the top of the immediately adjacent part of the elevation which is present on the distal side of this depression. If the latter was its location, then the anal pyramid consisted of small imbricating plates, not presenting a strongly radial arrangement. If the anus was located at the base of the depression, as more probably was the case, then nothing is known about the anal pyramid.

In *Cystaster granulatus* the anal pyramid is abruptly elevated near the middle of the posterior interambulacral area. It is formed of about 10 somewhat elongated plates, more or less overlapping laterally, so that part are exterior and part more or less interior.

24. Location of the Anus in the Agelacrinidae

Since the *Agelacrinidae* may be regarded as derivatives from a Cystidean type, it may be worth while to emphasize the location of the anus in the posterior interambulacral area, opposite the anterior ray. This is a frequent position of the anus among the *Diploporita*, in *Cystidea*. While a similar position of the anus is described by Bather (*The Echinoderma*, 1900, p. 53) in case of *Echinosphaera aurantium*, from the Ordovician of Europe, the anus in most *Rhombifera* has travelled toward the right, occurring between the right and right posterior branch of the ambulacral system in most *Glyptocystidae*, and between the anterior and right branches in the highly specialized genus *Cystoblastus*, from the Ordovician of Russia.

25. Origin of Ambulacral System of the Agelacrinidae

The fact that the lateral margins of the floor plates of the Ordovician *Agelacrinidae* passes beneath the adjacent margins of the interambulacral plates is opposed to their origin as exothecal plates, as in the *Rhombifera* among the *Cystidea*. The fact that in *Thresherodiscus*, the terminal parts of the branching rays rest upon the margins of ordinary thecal plates, merely depressing their exposed margins a little, suggests the origin of the floor plates as parts of the original thecal covering. The latter structure is

found among the *Diploporita*. Of course, there are no diplopores among the *Agelacrinidae*, and there are no brachioles, so that the *Agelacrinidae* probably originated from an earlier stock, but one in which pseudo-pentagonal symmetry already was present.

As regards the peristomial plates of the *Agelacrinidae*, those of *Thresherodiscus* are the most primitive. In those forms, however, in which the number of peristomial plates was small, as in *Agelacrinus pileus* (plate I, Fig. 5B), the primitive arrangement appears to have been a series of five plates of which the posterior was the largest. The next larger in size were the two plates on the anterior side of the peristomial slit—the plate between the anterior ray and the right ray, and the plate between the anterior and the left ray. The smallest plates of the peristomial series were between the bases of the left and left posterior rays, and between the right and right posterior rays.

While the earlier *Amphoridea* may represent the most primitive types among the *Cystidea*, it is evident that pseudo-pentamerism had developed among the *Cystidea* long before the *Agelacrinidae* deviated from this stock.

The *Edrioasteridae* may have had quite a different origin from the *Agelacrinidae*, since their floor plates are arranged in two series, one on each side of the ray, which alternate along the median line.

26. The Ornamentation of the Surface of the Thecal Plates

The surface of the thecal plates of *Agelacrinus cincinnatiensis* and of *Agelacrinus holbrooki* is essentially smooth. In some of the specimens of *Agelacrinus pileus*, however, the surface is covered by numerous closely arranged very minute pits, seen only under a lens. In specimen No. 13268-1-a, belonging to the American Museum of Natural History, these pits are shown on every exposed surface, including the peristomial plates, the lateral covering plates, the interambulacrals, the plates belonging to the anal pyramid, and the plates forming the inner band of the peripheral ring. Since the small marginal plates of the peripheral ring are not exposed, nothing can be definitely said regarding the latter, but probably the same minute pits are present at least on the larger ones of these marginal plates.

No definite ornamentation was noted on the surface of the plates of *Streptaster*.

In *Thresherodiscus*, there may have been minute granules on the surface of the larger interambulacral plates, but in the present weathered condition of the plates this can not be determined definitely.

I have seen nothing to suggest the presence of distinct and readily recognizable granules on any Ordovician species referred to *Agelacrinus* or *Lepidodiscus*. Such granules as occur on these species appear to belong to species of *Dermatostroma*, covering the surface of the *Agelacrinus* with a very thin, granule-bearing layer (plate I, Fig. 3B; plate III, Figs. 1, 4).

27. The Central or Substomial Cavity of Agelacrinus Pileus

In 1892, Miller and Faber described the lower side of the upper face of a theca of *Agelacrinus pileus* from near the top of the hills at Cincinnati, Ohio. The horizon probably was in the Corryville member of the Maysville. The specimen forms No. 8825 in the Faber Collection in Walker Museum, at Chicago University. In this description (*Journal of Cincinnati Society of Natural History*, vol. xv, p. 85, plate I, Fig. 10; see also plate I, Fig. 5A, and plate II, Fig. 4 of this Bulletin), the following remarks refer to the substomial chamber, as seen from below Explanatory comments are added by the writer in brackets.

> The coverings of the rays (the floor plates, as seen from below) are united near the center of the fossil by a subpentagonal rim, that extends deeper into the visceral cavity than any part of the internal (part of the) rays, and, we believe, extended to the very bottom of the test, and formed the part of the organism that adhered to the foreign object to which these animals attached. Three sides (the anterior sides) of this projecting rim are preserved and shown in the illustration, and the surface is flattened, as if for the purpose of attachment. Within this pentagonal rim there is a pit showing the five subovate mouths of the ambulacral canals, which are also indicated in the illustration.

Miller and Faber did not overestimate the value of this specimen since it is still the best specimen for showing the lower surface of the upper face of the theca. It needs, however, a much fuller description, and such a description is attempted here.

At the center of the theca, as seen from below (plate I, Fig. 5A), there is a substomial chamber or cavity from which the ambulacral rays radiate. The anterior part of the rim of this cavity has a form suggesting a pentagonal outline for the entire rim. This is owing to the fact that this part of the rim appears to be formed by the enlargement and lateral extension of the proximal floor plate of each of the three anterior rays, usually called the left, anterior, and right rays, or rays Nos. 2, 3, and 4. Even if eventually the homology of the rim plates with the proximal floor plates be disproved, the appearance of the rim plates is very well described by this supposed homology. If the specimen be held with the oral side upward, then the proximal floor plate of each of these anterior rays appears to widen rapidly so as to overlap the proximal floor plate of the neighboring ray; at the same time this proximal floor plate curves downward more or less vertically, so as to produce the rim-like effect, as seen from below. The outline of this rim is sufficiently straightened between the median parts of the left and anterior rays, and between the anterior and right rays, to suggest the pentagonal outline. As seen from below, each of the three proximal floor plates arches over the ambulacral groove to which it belongs, leaving an oval opening leading from the median groove in the ambulacral rays into the central substomial cavity.

It must be evident, however, in view of the long transverse peristomial slit, as seen from the exterior view of the specimen, that a corresponding transverse elongation of the substomial chamber must be expected from an interior view, and this is the case. The regularity of the supposed pentagonal outline is considerably disturbed by the acuteness of the angle at which the proximal floor plates of the posterior rays meet those of the lateral rays. This feature is best shown by specimens No. 13266-1-r and x, belonging to the American Museum of Natural History. In both of these specimens, the proximal floor plate of the right posterior ray (No. 5) meets that of the right ray (No. 3) at quite a considerable angle. It is assumed that a similar angulation existed at the angle between the left and left posterior rays. (Plate II, Fig. 3.)

The posterior margin of the substomial chamber, in the Miller and Faber specimen, is formed by a large quadrangular plate, which appears to be merely the lower part of the large quadrangular peristomial plate seen on the posterior side of the peristomial slit as viewed from the exterior. On its inner face, within

the chamber, this quadrangular plate is ridged somewhat like a letter W, the sides of the letter abutting against the thickened inner margins of the adjacent proximal floor plates. Toward the two grooves on the inner side of this posterior quadrangular plate, one on each side of the median ridge, project the strong median ridges of two plates, which, from interior view, have a triangular form, with the broad base against the sutures between the anterior and right proximal floor plates, and between the anterior and left proximal floor plates. These plates probably are merely the interior views of the two rhomboid plates (R and L) seen on the exterior view of peristomial area, and the vertical ridging prevents lateral displacement.

This leaves to be accounted for a peculiar margined depression along the proximal part of the right hand margin of the right posterior ray (No. 5), as viewed from below. This impression involves the two proximal covering plates on the left side of the right posterior ray, where adjoining the right margin of the large posterior peristomial plate, as seen from above. Possibly a duct passed by this path, but its presence could not be verified with confidence. (Plate I, Fig. 5A.)

There is no evidence of the base of this substomial chamber or cavity ever having served as a support of the theca, as suggested by Miller and Faber. It probably was underlaid by the central fleshy aboral face of the specimen. It served chiefly to strengthen the central parts of the upper part of the theca, in the peristomial region.

Moreover, there is no indication of any passage between the mouth and the anus. The gut appears not to have had any special protection apart from the rest of the soft parts of the animal. Moreover, the direction of torsion of the gut is unknown.

28. The Central or Substomial Cavity of Streptaster Septembrachiatus

The lower surface of the upper face of a theca belonging to some species of *Streptaster* is exposed fairly well on a rock fragment found 8 feet below the top of the Elkhorn member, in the upper part of the Richmond, at a small waterfall west of the home of John Miller, a short distance west of the Union road and north of the Eaton pike, about three miles west of Dayton, Ohio.

The original form of the theca was circular, but in its present condition it is somewhat distorted, one of the diameters being 25 mm., while the other, in a transverse direction, is about 20 mm. in length. The longest ray, measuring along the curvature, is 20 mm. in length. All of the rays are so strongly curved that the interambulacral areas are narrow even in the central parts of the theca. The posterior area is about 3 mm. in width. All of the other interambulacral areas are about 2 mm. in width.

At the proximal ends of the ambulacral rays, the floor plates enlarge laterally and also downward (plate I, Fig. 7A; also plate IV, Fig. 2), so as to form a marginal rim enclosing a central cavity, directly beneath the mouth. This part is well exposed but has been weathered so that the details can not be determined excepting for a few plates. The middle plate along the anterior part of the rim is formed by the modified proximal floor plate of the anterior ray. This plate is concave toward the cavity, and its lateral edges overlap the edges of the adjoining marginal plates, on the right and left parts of the anterior rim. Towards its anterior extremity, this plate narrows down to the same width and has the same transverse curvature as the other floor plates. The left part of the anterior margin of the rim, as seen from below is formed by a similar modification of the proximal floor plate of the right ray (No. 4), but the overlapping sides of this plate do not extend as far on the posterior side as on the anterior one. Posterior to the latter is the modified proximal floor plate belonging to the right posterior ray (No. 5).

On the right side of the anterior part of the rim of the substomial cavity, as seen from below, there is a modified proximal floor plate belonging to the left ray (No. 2). Immediately posterior to this should be the modified proximal floor plate belonging to the left posterior ray (No. 1), but the latter is badly weathered, and only the narrow distal termination of this plate can be identified with confidence. The posterior outline of the cavity is formed a mass of material in which it has not been possible to recognize any definite structure.

Immediately in front of the median part of the posterior part of the rim there is a vertical cavity, less than a millimeter in diameter, apparently leading to the oral surface of the theca. This aperture, as seen from below, is bounded on the left by a quadrangular plate filling in most of the lower left hand quarter

of the substomial chamber. On the left side of this quadrangular plate, near the junction between the lateral margins of the proximal floor plates belonging to the right and right posterior rays (Nos. 4 and 5), there is a broad inclined groove.

It has been found impossible to unravel the structure of the peristomial parts of the theca from the view of its under surface, as exposed within the substomial chamber as viewed from below. Apparently this peristomial part consists of a number of small plates instead of a few larger ones, but no definite structure has been recognized. Moreover, no apertures leading from the ambulacral grooves along the median parts of the rays, beneath the modified floor plates, as seen from below, into the substomial chamber, have been detected. Under these circumstances, it is not worth while to speculate regarding the use of the deep depression or aperture at the posterior margin of the substomial chamber, or the purpose of the inclined surface or broad groove on the antero-lateral side of the quadrangular plate filling the left posterior side of the substomial chamber, as seen from below. Possibly the gut twisted in a solar direction, and left the substomial chamber along this inclined surface, but the direction of the gut is unknown in the *Agelacrinidae*.

Description of Several Ordovician Agelacrinidae

29. The Use of the Generic Terms Agelacrinites and Lepidodiscus

Clarke has shown (*New Agelacrinites*, 1901, p. 193) that the type of *Agelacrinites*, the Devonian species *Agelacrinites hamiltonensis*, is characterized by the presence of mosaic interambulacral plates, with irregular polygonal outlines, and a more or less radial sculpture; also by narrow rays, and a well developed peripheral ring consisting of an inner band of large plates and a marginal zone of small plates.

From typical *Agelacrinites*, the Ordovician species formerly referred to *Agelacrinus*, merely a different spelling to the same generic term, differ in the presence of imbricating interambulacral plates, and wider rays. It should be noted also that the floor plates of *Agelacrinites beecheri* are narrower, and evidently support only one lateral covering plate on each side, instead of being

broader and supporting two covering plates on each side, as in the Ordovician species referred to *Agelacrinus*.

In *Lepidodiscus*, as defined by Clarke, all of the thecal plates are squamose and imbricating, and in one species, *Lepidodiscus alleganius*, these plates are present even on the aboral surface. The chief feature is the essential absence of a distinct peripheral ring with an inner band of larger plates and an outer zone of much smaller plates. As in other Devonian *Agelacrinidae*, the rays are narrow.

From typical *Lepidodiscus*, the Ordovician species recently referred by some authors to *Lepidodiscus*, in preference to *Agelacrinus*, are distinguished by the presence of the distinct peripheral band, and by broader rays.

From this it will appear that neither *Agelacrinus* nor *Lepidodiscus* are suitable terms for the Ordovician species hitherto referred to these genera, as pointed out by Clarke in 1901, and it will be necessary to propose a new generic term for the latter. In the present paper the term *Agelacrinus* is retained temporarily for the Ordovician species formerly described under that name, as being at least more noncommittal than *Lepidodiscus*, since the term *Agelacrinus* was long used in a very broad sense.

30. **Thresherodiscus ramosa**, Gen. et sp. nov.

(Plate I, Fig. 8; Plate III, Fig. 3)

An interesting *Edrioasteroid*, with branching ambulacral rays, a feature hitherto unknown in this group of *Echinoderma*, was found by the writer, during the summer of 1912, on Goat Island, northeast of the village of Little Current, the chief town on Manitoulin Island, Lake Huron, Ontario. The exact locality is at the point where the railroad from LaCloche Island strikes the northeastern edge of Goat Island. Here *Carabocrinus vancortlandi* is common 7 feet above the lake level. In the overlying strata, 4 feet thick, *Plectambonites curdsvillensis* occurs at various levels. The *Thresherodiscus* was found at a horizon belonging stratigraphically 18 feet above the lowest strata exposed at the edge of the lake. Here it was associated with *Cleiocrinus regius, Reteocrinus alveolatus, Cyclocystoides halli,* and a species of *Lichenocrinus*. Between 24 and 28 feet above the lowest horizon, *Glyptocrinus ramulosus* was represented by abundant remains of the

long, large column, and occasional parts of the basal portion of the cup. The southern exposures on Cloche Island evidently are of Black River age, and therefore these most northern exposures on Goat Island probably belong low in the Trenton section. They are correlated provisionally with the Kirkfield and Hull horizons of Ontario and the Curdsville bed in central Kentucky. The following is a description of the *Thresherodiscus ramosa,* here found.

Genotype, Thresherodiscus ramosa

The generic name is given in honor of Mr. and Mrs. J. B. Thresher, of Dayton, Ohio, in appreciation of the many years of encouragement given the writer in his efforts at scientific investigation. The type forms No. 8446 in the collections of the Canadian Geological Survey, in the Victoria Memorial Museum at Ottawa, Canada.

Theca discoid, 16 mm. in diameter. Upper surface gently convex, excepting at the sides where the slope becomes steep. Vertical height between 4 and 5 mm. Lower surface not exposed, apparently resting upon the surface of some bryozoan. Animal probably not permanently sessile, but capable of changing its location.

Mouth central. From this mouth three ambulacral rays diverge—an anterior, a right, and a left primary ray. The right and left primary rays form an angle of 150 degrees with each other; the anterior ray is directed sufficiently far to the left to make an angle of about 90 degrees with the left primary ray. All these primary rays bifurcate dichotomously at least twice, the first of these bifurcations taking place about 2 mm. from the center of the oral area.

Regarding the trimerous radial structure as primitive among the *Echinoderma,* and the more obvious pentamerism of this group as secondary, the correlation of the ambulacral rays of *Thresherodiscus* (Fig. 1) with those of other *Agelacrinidae* becomes obvious. Designating the left posterior ray of the ordinary *Agelacrinidae* as No. 1, and the other rays in succession in dextral order as 2, 3, 4, and 5, the last number is given to the right posterior ray. Using the same numbers for the rays of *Thresherodiscus,* the anterior primary ray (*A*) evidently corresponds to No. 3. The first branches of the right primary ray

(*R*) correspond to rays 4 and 5, and the first branches of the left primary ray (*L*) correspond to rays 1 and 2, using these numbers in dextral order, as heretofore. In the following lines the terms left posterior, left anterior, anterior, right anterior, and right posterior will be used to express the homologies of the rays here indicated.

The first dichotomous branching of the anterior ray takes place 2 mm. from the center of the oral area. The left and right branches of the anterior ray bifurcate again at distances of 3.5 and 4 mm. respectively from the first fork, the secondary branches (*s*) not exceeding 2.5 mm. in length.

Rays Nos. 1, 2, 4, and 5 bifurcate dichotomously (*a, p*) at distances of 2.3 to 2.6 mm. from their origin at the ends of the left and right primary rays, most of the branches varying in length

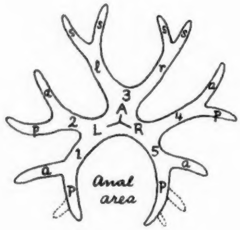


Fig. 1. Diagram of ray system of *Thresherodiscus ramosa*. *A, L, R*, anterior, left, and right primary rays. *1, 2, 3, 4, 5*, left posterior, left, anterior, right, and right posterior rays; *l, r*, left and right branches of anterior ray; *a, p*, anterior and posterior branches of rays *1, 2, 4*, and *5*.

from 3 to nearly 4 mm. The posterior interambulacral area contains the anus, on the side nearest the right posterior ray, as in other species of the *Agelacrinidae*. This posterior interambulacral area is of oval form, 4.5 mm. in width and nearly 7 mm. in length, following the curvature of the theca. The posterior branch of the right posterior ray, bordering the right posterior outline of the anal interambulacral area, appears to branch a second and third time, at distances of 2 and 4.5 mm. from the first fork of this ray, and similar forking may take place on the left posterior side of this anal interambulacral area, but the evidence for this is not perfectly clear.

Floor plates (plate I, Fig. 8, fl), forming the lower or thecal side of the ambulacral rays, large and extending the entire width of the ray. Their general outline is quadrangular. The lateral thirds of the width of each floor plate are flat, but the median third is distinctly furrowed by the ambulacral groove which is deeper toward the mouth but becomes quite shallow near the terminal branches. Following the floor plates from the mouth toward the extremities of the branches, the distal end of one plate is overlapped slightly by the proximal end of the next succeeding plate.

In the case of the anterior ray, the floor of the primary part appears to be formed by two plates, poorly exposed. The floor plates of the first branches are clearly exposed—three forming the floor of the right branch, and two forming the floor of the left branch. At the end of the left branch, a floor plate on the left overlaps a floor plate on the right, thus starting the secondary branches. The floor plates of the secondary branches number at least three or four, but at the tips of the branches the outlines of the floor plates are not clearly exposed, nor are they clearly differentiated from the adjacent marginal plates.

The floor plates of the left primary ray are not exposed but the length of this part is sufficient to admit of two plates. The primary part of the branch here designated as ray No. 2 appears to rest upon two floor plates. The anterior branch of ray No. 2 rests on at least four floor plates. The posterior branch of this ray rests on three distinctly grooved floor plates, beyond which are two or three thecal plates on which the grooving is faint. The anterior branch of ray No. 4 is supported on four floor plates of which the last is only moderately grooved; beyond this are about three thecal plates, belonging to the laterally elongated marginal series, which also show faint grooving. The floor plates of the posterior branch of this ray are not exposed.

None of the floor plates of the right primary ray, or of any of its branches, are exposed.

The entire width of the floor plates is covered by the ambulacral rays. The covering plates consist of two conspicuous lateral series (plate I, Fig. 8, c, c)—one series on each side of the ray, or of its various branches—and of numerous much less conspicuous central covering plates, to a large extent also arranged in two series, along the median part of the rays. The lateral covering plates rest upon the extreme sides of the floor plates. The lat-

eral edges of these lateral covering plates overlap each other, the distal side of one plate being covered by the proximal side of the next succeeding plate. The general form of the lateral covering plates is elongate pentagonal, the tips alternating with the central covering plates. About six lateral covering plates occupy a length of 2 mm. This suggests the presence of at least two lateral covering plates along the side of each floor plate, probably decreasing to one on each floor plate as the smaller extremities of the last branches are reached.

In one respect the structure of the rays of *Thresherodiscus* differs strongly from that of *Agelacrinus cincinnatiensis*, *A. pileus*, *A. holbrooki*, and probably also of other Ordovician species usually referred to *Agelacrinus* or *Lepidodiscus*. There is no known prolongation of the lateral covering plates extending laterally beneath the adjacent interambulacral plates.

The central covering plates of the ambulacral rays, or rather those parts of these plates which are visible, are very small and the definite determination of their arrangement is difficult. Along one part of one ray these central covering plates are arranged in two series, alternating both with each other and also with the tips of the lateral covering plates. However, there are other parts of the specimen in which the central plates appear to be more numerous than the lateral ones, and in which the arrangement, in consequence, appears less regular.

The interambulacral plates differ conspicuously in size. Of these, the central plates (plate I, Fig. 8, ia) are much larger, distinctly squamose, and imbricating, the distal end of one being overlapped by the proximal end of the next. Owing to the rather numerous branches of the rays, the primary interambulacral areas are so much divided and the individual parts so narrow that the large squamose plates along the center either form an approximately straight row, or a more or less strongly zigzagging series, alternation being always conspicuous at the distal end of the series, where the large, central interambulacral plates merge into the numerous laterally elongated plates that belong to the inner band of the peripheral ring. The nearest approach to a single straight series of large plates is found in the interambulacral space starting at the point of divergence of the proximal parts of rays Nos. 1 and 2, and in that which starts in the angle between rays Nos. 3 and 4. The approximately straight part of these series is

confined to only about four plates, the more distant interambulacral plates alternating distinctly in all cases.

Surrounding the central series (plate I, Fig. 8, ia) of large squamose, imbricating interambulacral plates, in each division of the interambulacral areas, there is a continuous series of much smaller bordering plates (plate I, Fig. 8, b), arranged with their longer axes more or less perpendicular to the adjoining branches of the ambulacral arms. Toward the central part of the theca, these bordering plates usually vary from one-third to one-half of a millimeter in length, while the number along the side of the ambulacral rays is about equal to that of the adjacent lateral coverings plates, or is moderately greater. Usually there is only a single series of bordering plates between the various branches of the ambulacral rays and the conspicuous plates along the center of the included parts of the interambulacral areas. The most conspicuous deviation from this arrangement in a single series is found in the anal interambulacral area, which is distinctly wider than any of the other areas, and in which the additional space, on both sides of the central series of large plates, is occupied by additional, but more or less irregularly arranged, bordering plates. These bordering plates may be traced almost to the extreme ends of the smallest branches of the ambulacral rays, and form the readiest guide to the course of the various branches of the rays, when the covering plates are absent, since the floor plates here so closely resemble the adjacent thecal plates.

The anus is situated in the posterior interambulacral area. This is the area in which the bordering plates, between the large squamose central plates and the adjoining branches of the ambulacral rays are so numerous. The area is rounded oval in form. The exact location of the anus is on the right side of the series of large central plates, near mid-length of the area. Apparently it is at the base of a deep depression but this may be due only to muscular contraction on the death of the animal. On the distal side of the anus the plates are of small size, gradually merging into the laterally elongate plates belonging to the upper rows of the marginal series. If the anus was protected by a pyramid of small plates, this pyramid is concealed at present at the base of the anal depression.

The mouth was located centrally. The peristomial plates are not preserved in the only specimen known. The lateral covering

plates of the left primary ambulacral ray may be traced on the anterior side, in a proximal direction, as far as the first lateral covering plate at the proximal end of the anterior ray, while on the posterior side of this left primary ray they may be traced to a point on the posterior side of the mouth, opposite the median line of the anterior ray. These lateral covering plates show no enlargement along the oral slit, so that it is regarded as very probable that the peristomial plates did not differ conspicuously in size from the adjoining lateral covering plates, as is the case in *Agelacrinus pileus*, and to some extent also in *A. cincinnatiensis*, and probably also in other Ordovician species referred to *Agelacrinus* or *Lepidodiscus*.

Beyond the extremities of the remote branches of the ambulacral rays, there is a marginal or peripheral zone of imbricating squamose plates resembling those of the inner band of the peripheral ring of other *Agelacrinidae*. Only the proximal ends of these plates are well exposed, but these are sufficiently extended laterally to indicate that their general form is short but broad. In a proximal direction these marginal plates are successively larger in size, merging gradually into the series of large central interambulacral plates. In a distal direction, on the posterior border, the marginal plates of the peripheral ring become successively shorter and more numerous, and resemble the marginal plates of *Lepidodiscus cincinnatiensis*, as illustrated by Hall, in Figure 7 on plate 6, of the *Twenty-fourth Annual Report of the New York State Museum*. They are ornamented by short parallel vertical ridges or elongated granules. On the anterior border, there is a series of narrow, but elongate imbricating plates, resembling the narrow imbricating scales of the cup at the base of an acorn, or the plates at the base of the margin of *Streptaster vorticellatus*, as illustrated by Hall in Figure 12 of the plate cited above. There is no means, at present, of accounting for these differences in appearance of the smaller plates along different parts of the border. Of the larger plates, forming the inner band of the peripheral ring, there appear to be about six rows, counting in a diagonal direction, beneath which, along the anterior margin, there are three or four rows of the smaller narrow plates. Along the posterior border, there are five or six lower rows of smaller plates, but these are laterally elongated as in the case of the overlying rows of larger sized peripheral plates.

No surface ornamentation was detected upon any of the larger

interambulacral plates. There is a tendency toward a ridge parallel to the longer diameter of the plate in case of the bordering plates, along the sides of the rays. There is no evidence of pores or of a madreporite.

Thresherodiscus differs from all other *Edrioasteroidea,* hitherto described, in the presence of branched ambulacral rays, and in the very pronounced trimerous origin of these rays. The strong differentiation between a central series of large squamose imbricating interambulacral plates and the smaller bordering interambulacral plates is noteworthy.

The presence of a single row of large floor plates is an interesting feature, but is known also in *Agelacrinus cincinnatiensis, A. holbrooki, A. pileus, A. faberi,* and *A. austini.*

It is evident that *Thresherodiscus* finds its nearest relatives among the *Agelacrinidae,* but it probably had quite a different origin from the Ordovician species usually referred to *Agelacrinus.*

31. **Agelacrinus vetustus,** sp. nov.

(Plate III, Fig. 1)

For ten years I have had in my possession a specimen of *Agelacrinus* which is of interest chiefly because it was found in the Greendale or richly fossiliferous member of the Cynthiana formation, on the south side of the Kentucky River, at Clays Ferry, 14 miles southeast of Lexington, Kentucky, opposite the southeastern corner of Fayette County. It occurred in the fossiliferous strata between 38 and 69 feet above a massive limestone layer, near a road side watering trough. The specimen is attached to a pedicel valve of *Rafinesquina,* and apparently is covered by the thin, densely papillate stroma of some *Dermatostroma,* which obscures the outlines of all of the thecal plates excepting those belonging to the ambulacral series, and even here tubercles are found on the outer, exposed faces of the lateral covering plates. This papillate stroma does not extend from the theca of the *Agelacrinus* on to the surface of the *Rafinesquina,* upon which it rests. In fact, for some reason this stroma does not actually reach the extreme margin of the theca but is separated from the latter by a very narrow space along which the vertical ridges belonging to the outermost rows of very small marginal plates are exposed. Ridges of a similar sort are illustrated by Hall. *Twenty-fourth Report of the New York*

State Museum, by figure 12 on plate 6; which is reprinted as figure 4 on plate 6 of this BULLETIN. The papillae on this stroma are largest nearer the margin of the theca, becoming smaller in the interambulacral spaces and on the lower parts of the covering plates. The ambulacra, mouth, and anal passage apparently were not obstructed, or at least were only partially obstructed.

The anus is located in the center of the posterior interambulacral area, the papillate stroma constricting the passage and rising slightly around it. This suggests that the *Dermatostroma* spread over the theca during the life of the animal. The peristomial plates consist of a broad posterior plate and of two diagonally rhomboid anterior plates, as in *Agelacrinus pileus*. The upper margin of the posterior plate, as viewed from above, is broadly V-shaped and an angulation probably extended along its median line.

As far as may be determined, through the covering papillate stroma, the upper plates of the marginal series and the interambulacral plates corresponded in size and form to those of *Agelacrinus pileus*, and it is to this species that the Clays Ferry *Agelacrinus* is most closely related.

Theca very depressed convex, circular in outline, 12 mm. in diameter and about 2 mm. in height at the junction of the rays. Rays moderately curved, four sinistral and one dextral. Four of the interambulacral areas at present are depressed but this depression evidently took place after the death of the animal. The anterior rays meet the marginal rim at angles varying from 30 to 50 degrees. The left posterior ray meets the rim at an angle of about 70 degrees and the right posterior ray forms an angle of about 30 degrees. The tips of none of the rays are extended parallel to the peripheral ring, as in *Agelacrinus cincinnatiensis*, and as also to some extent in *A. pileus*.

The most characteristic feature of this Clays Ferry species is presented by the lateral covering plates. The ambulacral rays apparently were somewhat elevated as in *A. pileus*. The lateral covering plates on opposite sides of the ray alternate with each other as in other species of this group. Along the upper surface of the rays, however, they appear like a series of short ridges arranged transversely to the length of the rays. In their narrowness and length these lateral covering plates differ conspicuously from those of *Agelacrinus pileus*, in which these plates are

shorter and broader, and terminate abruptly in acute points, when viewed from above. On the anterior and left anterior rays, there are about twelve or thirteen pairs of lateral covering plates; on the right posterior ray there are about eleven pairs; on the two remaining rays, there are about ten pairs.

The papillae of the *Dermatostroma* number about six or seven in the length of 1 mm. in the interambulacral areas, and four or five in the same length at some points along the margin.

The animal probably was capable of shifting its position from place to place, and, in consequence, the *Dermatostroma* did not extend from the theca of the *Agelacrinus* over on to the shell of the *Rafinesquina*.

The small curvature of the rays is a primitive character. This character should be sufficient to distinguish *Agelacrinus vetustus* from *A. pileus*, in which the distal end of the rays turns sufficiently to become parallel to the peripheral band for a short distance. An even more primitive condition is shown by the Trenton *Agelacrinus billingsi*, Chapman, in which the rays are sharp and quite straight, the distal end abutting against the peripheral ring.

Agelacrinus pileus is listed by Nickles from the Corryville member of the Maysville but I have seen specimens on the same slab with *Plectorthis plicatella*, thus suggesting an earlier age for some of the specimens.

Agelacrinus vetustus is merely another example of the rather numerous cases in which typical Maysville species are represented in the Cynthiana formation by closely similar forms.

32. **Agelacrinus faberi,** Miller

(*Plate I, Figs. 3 A, B, C; Plate III, Fig. 4*)

(*Journal, Cincinnati Society of Natural History, vol. XVII, p. 156, Plate 8, Figs. 24, 25, 1894*)

This species was found by C. L. Faber "in the extreme upper part of the Hudson River (Cincinnati) Group, about half way bebetween Osgood and Versailles, Indiana." The type, at present, forms No. 8821 in Walker Museum, at Chicago University. It probably belongs to the Whitewater division of the Richmond, immediately above the typical Saluda.

The type is too poorly preserved to merit description. It undoubtedly would not have been described had it not been for

the presence of numerous tubercles supposed to belong to the original ornamentation of the plates. In the original description it is stated that "the surface of all the plates is densely and beautifully tuberculated. This species is distinguished from all others, in rocks of the same age, by the tuberculated plates." As a matter of fact, all plates are not densely and beautifully tuberculated, and it is doubtful whether the tuberculation belongs to the plates, as an organic part of the same.

If I have correctly interpreted the orientation of this specimen, then the transverse slit along the oral parts is parallel to a line drawn diagonally across the brachial valve of the *Hebertella alveolata*, upon which the specimen rests; this line is to be drawn from the right hand end of the hinge line to the left antero-lateral angle of the valve. The anterior parts of the theca lie nearer the anterior margin of the valve. The broad, peristomial plate, posterior to this slit, and the right one of the two plates immediately anterior to this slit appear to be preserved. There appear to be traces of the two posterior rays enclosing the supposed anal interambulacral area, but most of the plates within this area are missing and those present are more or less displaced and tilted at various angles, making their definite interpretation impossible.

The right anterior, and anterior rays are strongly curved in a sinistral direction, but only the terminal parts are even fairly preserved. At the proximal end of the anterior ray, apparently one or two floor plates are exposed. Several floor plates belonging to the left anterior ray also appear present. They form a single series, are depressed along the center, are about as long as wide, and overlap each other in a proximal direction. Possibly the floor plates described by Meek (*Ohio Palentology*, vol. I, p. 55) belong to this Richmond species. Nearly all of the plates belonging to the left posterior interambulacral area of *Agelacrinus faberi* are missing.

The plates of the interambulacral areas are of medium size, but the first circle of plates immediately exterior to the terminations of the ambulacral arms, belonging to the inner band of the peripheral ring, consists of large transverse plates, varying between 3 and 4 mm. in width. Exterior to these are about two circles of plates, nearer 2 mm. in width, between which and the margin there are two, three, or four successively smaller plates. In the original description it is stated that this species is "distinguished

from *Agelacrinus cincinnatiensis* and *A. pileus* by the absence of the great number of small plates that form the periphery in those species, and also by having the larger plates of the body, in the rim, that surrounds the ends of the rays." However, the plates forming the inner band of the peripheral ring do not appear unusually large to me, and the smaller marginal plates seem few in number, apparently merely because most of them have fallen off.

As already mentioned, it is very doubtful whether the tuberculation can be considered a part of the original ornamentation of the thecal plates. The tubercles resemble very much those of *Dermatostroma papillata*, James, although of smaller size and more closely approximated. In *Dermatostroma papillata*, the tubercles number about three or three and a half in a length of 1 mm., while those on the plates of *Agelacrinus faberi* number about five in the same length. The reason for interpreting these tubercles as due to the presence of *Dermatostroma* are the following. The tubercles on the plates are arranged more or less in rows. On the larger plates, along the posterior margin, these rows appear in several cases to pass from plate to plate, and are not interrupted at the margin of the individual plates. Where the imbricating plates are separated from one another, these tubercles, in a number of cases, are seen to be present also between the dislocated plates, where evidently they would interfere with the close fitting together of the plates during the life of the animal. Moreover, along the left anterior margin, the tubercles hide the limits of even the larger plates, as though a thin tuberculous stroma had passed over these plates, and also over the terminal parts of the anterior ray, on to the adjacent parts of the interambulacral area. Finally, on some plates, apparently as well preserved at the rest, no tubercles are present or these are only faintly represented, as though in initial stages of growth, while adjacent plates of the same series have tubercles. Until other specimens at the same horizon, are found, in which the tubercles can be demonstrated as original parts of the surface ornamentation, I shall regard this feature of the type specimen as due to the presence of some *Dermatostroma*.

The only surface ornamentation with which I am familiar among Ordovician species usually referred to *Agelacrinus* or *Lepidodiscus* is that of *Agelacrinus pileus*, and this appears minutely and irregularly pitted, rather than tuberculated.

Under these circumstances, *Agelacrinus faberi* can not, as yet,

be considered a well established species. It has already been noted that the specimen described by Meek in the *Paleontology of Ohio*, vol. 1, p. 55, in 1873, from the upper part of the Richmond group, at Richmond, Indiana, probably belonged to the same species. Its nearest relative appears to be *Agelacrinus pileus*.

33. **Agelacrinus austini,** sp. nov.

(*Plate VI, Figs. 1A,B,C.*)

This species is characterized chiefly by its small size. The largest specimen at hand does not exceed 10 mm. in diameter. The upper surface is of very moderate convexity. In a specimen 8.5 mm. in diameter (fig. 1A on plate VI), that part of the ray which is parallel to the inner band of the peripheral ring is about as long as the straight, proximal part, radiating directly from the oral center. In a specimen 7.5 mm. in diameter (fig. 1C, on pl. VI), the rays are more gently curved and meet the peripheral ring at an acute angle without being strictly parallel to it for any distance. In a still smaller specimen, 6.5 mm. in diameter on the same support as the original of figure 1C, the left posterior ray, No. 1, is almost straight, and the remainder are but very moderately curved, meeting the peripheral ring at rather obtuse angles, compared with the rays of larger sized specimens. The exposed part of the lateral covering plates is ovate-triangular in form, and the spaces between adjacent plates are occupied in each case by one of the central or median series of covering plates, of which a relatively greater length frequently is exposed than in the case of any other known species. Commensurate with the small size of the specimens, the number of the squamose interambulacral plates is rather small. The anal pyramid consists of an outer circle of 6 ovate-triangular plates, between which can be seen glimpses of an inner circle, probably of about the same number. The inner band of the peripheral ring consists of one circle of large plates, considerably extended laterally. Above this is a circle of smaller plates graduating into the interambulacral series; and below is a third series graduating into the successively smaller plates forming the outer or marginal part of the peripheral ring.

The conspicuousness of the larger plates of the inner band of the peripheral ring of Ordovician species referred to *Agelacrinus*

usually is not a specific characteristic but is merely an indication of the degree to which these plates are exposed, as the result of being drawn apart in a radial direction by means of tension. In specimens of *Agelacrinus pileus,* resting upon an inclined surface, for example in figure 1 on plate II, this tension usually is along the upper margin of the sloping specimen. In specimens resting upon a flat surface, with the outer margin of the peripheral ring widely extended, the plates forming the inner band of the peripheral ring often are well exposed along the entire circumference. In the case of *Agelacrinus austini* also there is considerable variation in the conspicuousness of the plates forming the inner band, and no features are noticed in this connection which may be regarded as specific. As in other species, the marginal plates are successively smaller, those forming the outer row being very narrow and elongated in a vertical direction.

Peristomial plates not clearly defined in the specimens at hand but believed to include plates corresponding to L, R, and P, in figure 5B, on plate I of this paper.

Inferior aspect of upper part of theca (fig. 1B, on pl. 6) as in figure 3 on plate II, which is supposed to be the inferior aspect of a specimen of *Agelacrinus pileus.* Floor plates of rays 4 and 3 distinctly defined along the entire length of the rays. All of the floor plates of ray 1 are present; of these the proximal floor plate is considerably displaced, and the rest are slightly disjointed. They are strongly arched, as viewed from below, evidently consist of a single series of plates along each ray, and permit no glimpse of the basal extensions of the lateral covering plates. The proximal floor plate of ray No. 3 overlaps the adjacent edges of rays No. 4 and 2.

Specimens found in the upper part of the Whitewater division of the Richmond, four and a half miles northwest of Wilmington, Ohio, at the *Drepanella richardsoni* horizon, by Dr. George M. Austin, of Wilmington, and belonging to his collection.

34. **Agelacrinus holbrooki,** James

(Plate I, Figs. 1 A–F; Plate IV, Fig. 1)

(Paleontologist, No. 1, p. 2, 1878,

Journal, Cincinnati Society of Natural History, vol. X, p. 25, Figs. A, B, 1887)

A specimen of *Agelacrinus holbrooki,* from the James collection, is in the Walker Museum at Chicago University, and is numbered 1004. I strongly suspect that this specimen is the type, for the following reasons. The left anterior ray is preserved almost entire. The proximal part of the left posterior ray for a distance of about 12 mm. from the probable center of the oral parts is missing. Of the right posterior ray only the terminal U-shaped part is present; the remainder, from the oral parts to that part which is about as far distant as the more remote part of the anal opening, is missing. There is no trace of the right anterior ray, of the interambulacral areas above or below this ray, or of the oral parts. Only the distal, U-shaped part of the anterior ray is present, but the proximal part of the left anterior interambulacral area seems sufficiently preserved to indicate with some exactness the direction of the proximal part of the anterior ray. If, without giving any attention to the orientation of the rays, the specimen be turned so as to place at the top the exposed part of the fragment of pedicel valve of *Rafinesquina alternata,* upon which the specimen rests, then an outline similar to that of the published figure of the type is presented; that part of the margin of the theca which is at the top curves outward in a concave manner, and that part which is at the bottom curves downward and inward, so as not to be exposed. In that position, however, the orientation of the rays is different from that presented in the published figure of the type. I strongly suspect that the artist took considerable liberties with the specimen, first drawing the general outlines and general form of the specimen correctly, and then twisting the specimen through an angle of about 60 degrees to the right before putting in the details of the rays and interambulacral areas.

One of the most characteristic features of *Agelacrinus holbrooki* is the strong convexity of the upper surface of the theca. The greatest diameter of the specimen is 30 mm., and this is the diameter also in a transverse direction. The height is about 16 mm., the theca rising rather abruptly from the margin, thus giving it the sub-globose surface noted by James. Ambulacral rays rising but

slightly above the general convexity of the theca. At their distal ends they extend parallel to the marginal series of plates only for short distances; the two posterior rays, for about 5 or 6 mm.; the left anterior ray, for 3 or 4 mm.; and the anterior ray, for about 8 or 9 mm. Then the different rays curve strongly upward and around, so that the tips, if extended in a straight line, would strike the proximal part of the rays at points nearer than the oral center of the theca. The length of these recurved tips of the rays varies between 4 and 5 mm. The lateral covering plates are elongate triangular, the spaces between the tips being occupied by smaller and more centrally located covering plates. Covering plates belonging to the central series crowd in locally between the lateral plates, especially along the outer or convex outlines of the rays, at the points of greatest curvature. Along the inner or concave curve of the anterior ray, of the specimen here described, the covering plates have been weathered away, exposing the floor-plates of this ray. These floor plates are quadrangular in form, are 1.5 mm. in length, and 2 mm. in width. Five consecutive floor plates are visible. A distinctly defined groove, half a millimeter in width, extends along the median line of the floor plates. The lateral covering plates rest upon the sides of the floor plates. In the case of three of the floor plates, there appears to be a shallow longitudinal groove along that side of the floor plate which is on the inner or concave side of the curvature of the ray. It is probable that this lateral groove extends along the entire length of the ray, and that it occurs also on the opposite side of the ray. From the basal part of the lateral covering plates along the convex side of this ray, there extends a short projection, about two-thirds of a millimeter in length, which projects outward and downward at a low angle, but sufficient to pass beneath the nearest interambulacral plates. These basal projections are narrower than the width of the lateral plates and probably offered attachment to the muscles drawing the basal projections downward and the tips of the lateral covering plates, on opposite sides of the ambulacra, away from each other.

The interambulacral plates are arranged in rows crossing each other diagonally. Those in the left posterior interambulacral area are best preserved. Their general form is more or less rhombic, with sufficient of the top and bottom angles truncated in some plates to suggest an hexagonal outline. Along the margins of the interambulacral areas, the plates are smaller and their outlines

more irregular. At their margins the scales are closely appressed, the proximal parts of each scale overlapping the distal outlines of the next scale, in a direction toward the central part of the theca, although the amount of overlap is small. Strictly defined, the interambulacral plates are imbricating, and not mosaic, at contact.

Only the lower part of the anal region is preserved in the specimen. Several of the triangular plates of the anal pyramid are present. The adjoining plates are small, forming a very narrow band on the lower left side of the pyramid, widening on the lower right side toward the termination of the right posterior ray. This part is well figured by Clarke, in his paper on *New Agelacrinites*, in Bulletin 49, New York State Museum, p. 189, Fig. 2, 1901, (reprinted as Fig. 1c on plate VI of this BULLETIN) illustrating specimen No. 40744, in the United States National Museum, which is labelled as coming from Morrow, Ohio. This probably was the locality from which the type of the species was obtained, the collector, Professor Holbrook, having lived at Lebanon, Ohio. Morrow was the type locality also of *Agelacrinus warrenensis*. It was a well known collecting ground.

The marginal parts of the type specimen, as here identified, below the distal parts of the ambulacral rays, consist of two series of plates, grading into each other. Those immediately below the rays are of small vertical height but of considerable lateral extent. They are arranged in three or four rows, the plates becoming successively smaller, and grading into about three rows of much smaller plates, resembling in form the overlapping scales of an acorn cup.

Agelacrinus holbrooki is listed by Nickles from the Corryville division of the Maysville.

35. **Agelacrinus warrenensis,** James

(*Plate I, Figs. 4 A, B*)

(*Paleontologist, No. 7, p. 58, Plate II, Figs. 3, 3a, 1883*)

The following is the description presented by James:

Body circular, varying in diameter from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch or more. Attached to the convex valves of Strophomena (known at present as Rafinesquina), and, probably, other foreign substances; the under side concave, or otherwise, conforming to the surface grown upon. Disc composed of squamiform plates, overlapping inward from the periphery;

the plates of the outer margin very small and arranged in a narrow rim all around, the larger plates taking their place abruptly. About one line or a little more inward the surface becomes suddenly depressed, causing quite a sharp outward ridge, in most cases all round, by the projecting edges of the plates; and then rises, gently at first, but abruptly nearer and to the center, forming a somewhat prominent dome. The rays or arms nearly hidden by the imbricating plates in all the specimens examined; but occasionally some of the arms are partly but indistinctly shown, as is the case in the figured specimen. The ovarian aperture (anus) is hidden, probably, in the same way, it not being shown in any one of the specimens. All but one of the ten examples used for this description show the above specified characters, and that one is, evidently in an abnormal condition by lateral pressure.

Found by Dr. T. D. Dyche, of Lebanon, Warren County, O., in beds of the Cincinnati Group, equivalent to the tops of the hills at Cincinnati. The type specimens are in Dr. Dyche's fine collection.

According to Dr. Dyche, the type locality was a short distance up a small branch entering Second Creek at the first bridge east of Morrow, in Warren County, Ohio. The types were associated with *Dalmanella multisecta*, in the same rock. Two of the type specimens were presented to me by Dr. Dyche.

The presence of *Dalmanella multisecta* suggests the Fairmount member of the Maysville, since nothing lower than this member is shown along Second Creek.

At the same locality, east of Morrow, I have collected *Phylloporina clathrata*, *Plectorthis equivalvis-latior*, *Plectorthis equivalvis-pervagata*, *Playtstrophia* of the *ponderosa* type but rare, *Rafinesquina squamula*, *Zygopira cincinnatiensis* large, *Protowarthia morrowensis* (= *cancellata*), *Dalmanites carleyi*, and an *Isotelus* with a genal spine three-fourths of an inch long. About a mile east of Morrow, *Rafinesquina ponderosa*, characterizing the Bellevue horizon, is common. At a higher level the Corryville comes in.

The impression produced by the types of *Agelacrinus warrensis* is that of a suite of young individuals of *Agelacrinus cincinnatiensis*. As far as the sudden depression within the peripheral ring and the dome-like elevation at the center are concerned, these are not diagnostic features at all, but merely indications of rapid decay of the underlying viscera after the death of the animal, the inner band of the peripheral ring and the central or substomial chamber being most rigid and retaining their form best. Moreover, the ambulacral rays and the anus are hidden only in the

sense that they can not be located readily in specimens which have their thecal plates more or less disarranged, and this is true of the types of *Agelacrinus warrenensis*.

An excellent young specimen of *Agelacrinus cincinnatiensis* is preserved in the American Museum of Natural History, and forms No. 1194–IV of that collection. It is 10 mm. in diameter, rests upon a *Rafinesquina*, and displays five rays, one of them dextral. The tips of the rays already are sufficiently curved to become parallel to the peripheral band. An examination of this specimen will readily illustrate how difficult it would be to recognize the rays if the thecal plates were only moderately disarranged while the disarrangement of the thecal plates of the types of *Agelacrinus warrenensis* was fairly considerable.

36. **Streptaster**, Hall, generic characteristics

The term *Streptaster* was proposed by Hall in 1872 as a subgeneric term under *Agelacrinus*, and was founded on *Streptaster vorticellatus*, Hall, at that time the only species known. Later, in 1878, a closely related species, *Streptaster septembrachiatus*, was described by Miller and Dyer. Since both species had all of the rays sinistral, this appeared to be the most striking characteristic of the genus. In the present paper, however, a species with the right posterior ray turned in a dextral direction is described, so that this feature looses in diagnostic value. .

The chief characteristics of *Streptaster*, as far as known at present are the following.

Interambulacral areas very narrow, composed of a mosaic of small polygonal plates. Ambulacral rays very prominent and narrow, strongly curved, consisting of long, linear, lateral covering plates suggesting vertical palisades on lateral view, and enclosing high but very narrow ambulacral spaces. Floor plates small, each floor plate supporting two covering plates, one on each side. These floor plates overlap strongly in a proximal direction, and are so small that the bases of the covering plates must be almost in contact with each other. Peripheral band of plates distinctly defined, with larger, wide plates toward the top of the band, and with smaller, scale-like plates toward the margin, as in Ordovician species referred to *Agelacrinus* and *Lepidodiscus*.

37. **Streptaster reversata,** sp. nov.

(*Plate IV, Fig. 3*)

A single specimen of *Streptaster* was found 2 miles west of Million, in Madison County, Kentucky, west of trestle No. 51, in strata regarded as Middle Eden. Million is a railroad station, about 5 miles northwest of Richmond. About a mile southeast of Million, where the pike to Richmond crosses the railroad, is the home of George Million, and directly northeast of the house, along the railroad, is exposed the upper part of the richly fossiliferous Eden, directly below the poorly fossiliferous, massive, very fine grained Paint Lick or Garrard sandstone. Here the upper part of the richly fossiliferous Eden contains *Strophomena hallie, Platystrophia ponderosa, Fusispira terebriformis, Amplexopora septosa, Constellaria prominens, Dekayella ulrichi, Escharopora falciformis, Hemiphragma* sp., *Heterotrypa* sp., and *Perenopora vera.* Westward, along the railroad, as far as Million, a similar fauna occurs, giving place gradually to lower horizons in the Eden, on approaching the Tunnel, 1 mile northwest of Million. An eighth of a mile west of the Tunnel, at the home of Marion Newby, the lower part of the Paint Lick or Garrard sandstone is exposed far above the railroad level, while the lower parts of the Eden are seen near the track. A short distance west of this locality, *Strophomena millionensis* is found with an occasional specimen of *Trinucleus concentricus. Callopora sigillarioides, C. communis,* and *Eridotrypa briareus,* associated with *Cyclonema* and *Hebertella,* occur in the vicinity of Whitlock station; and, at bridge 51, a tenth of a mile west of the station, a small *Platystrophia* also is found. West of bridge 51, the *Streptaster* occurred, associated with *Callopora communis* and *Eridotrypa briareus.* The rock does not resemble the Greendale member of the Cynthiana formation until farther westward, so that the horizons exposed at the *Streptaster* locality may include both the Eden and the Rogers Gap member of the Cynthiana. The margin of the *Streptaster* rests upon a *Ceramoporella,* from which its Eden age was assumed. This identification of the horizon may require revision.

Anal interambulacral area quite well exposed. Left posterior ray about 14 mm. in length, of which the terminal part, for a distance of 4 mm., is parallel to the border. The right posterior ray is about 17 mm. in length. About 9 mm. from the proximal end,

the ray almost reaches the border, is parallel to the latter for a distance of 3 mm., and then curves toward the mid-length of the left posterior ray, terminating on contact with the latter at a point about 4 or 5 mm. from the proximal end of the latter. Between the recurved part of the right posterior ray and the adjacent parts of the left posterior ray, the intervening part of the posterior interambulacral area is reduced to a narrow, curved area, about half a millimeter in width, occupied by about two irregular rows of plates which are widened in a direction parallel to the rays, attaining a width of two-thirds of a millimeter. This series continues distally as a single irregular row between the strongly curved part of the right posterior ray and the much larger plates of the border.

The remaining, and much larger part of the posterior interambulacral area is bordered for three-fourths of its outline by the right posterior ray, only the proximal half of the left outline being in contact with the left ray. This part of the area is 8 mm. in length and slightly over 3 mm. in width. The anal pyramid occupies practically the entire width of the interambulacral area, between 2 and 5 mm. from the proximal ends of the posterior rays. The length of the pyramid is about 3 mm. and its width, 2.5 mm. About thirteen plates belong to this anal pyramid, converging toward the center, but it is not certain that all of them actually reached the center, Perhaps five of these plates merely act as supports to those lying nearer the center, but this can be determined only from other specimens. The interambulacral plates covering that part of the area which lies on the proximal side of the anal pyramid, all are of very small size. On the distal side of the pyramid, the interambulacral plates vary very much in size. The two largest attain a diameter of 0.75 mm. The next in size scarcely attain a diameter 0.5 mm., while most plates vary between 0.25 and 0.33 mm. All of these plates are more or less irregularly arranged, the two largest plates lying nearer the anal pyramid, along the median line of the area. The plates appear to be polygonal and arranged in a sort of irregular mosaic.

Only the distal part of the left lateral ray (No. 2) is present. This part is 9 mm. in length. The proximal part of the interambulacral area between this ray and the left posterior one is scarcely 1 mm. in width, and is occupied by 3 or 4 irregular rows of polygonal interambulacral plates, a quarter of a millimeter in diameter,

also arranged in mosaic. This interambulacral area narrows to a single row of plates distally.

Only the tip of the anterior ray, for a length of 1.5 mm., is preserved.

A single large prominent plate extends from the proximal end of the right posterior ray toward the anal pyramid. The homology of this plate is unknown.

The lateral covering plates are long and linear, and are sufficiently erect and parallel to produce the palisade effect characteristic of the genus. The longer ones slightly exceed 2 mm. in length, and about four lateral covering plates occupy a length of 2 mm. At their tips they are rather abruptly truncated, presenting a triangular transverse outline along the crest of the rays. The acute angles of these plates alternate along the median line of the rays.

Peripheral ring consisting of two zones. Of these the upper zone or inner band consists of comparatively strong plates, considerably extended in a lateral direction, but exposing only their outer edges. From these edges they are inclined toward the interior at angles of about 35 degrees with a horizontal plane. Although these stronger plates are arranged in diagonal lines, they may be said to form about five circular rows, the upper plates being considerably larger, the largest attaining a width of 4 mm. Even in the second lowest row some of the plates have a width of 2.5 mm. In the lowest row of the larger plates the width is about 1 mm. These larger plates formed the less flexible support for the upper part of the theca. Below this was the much more flexible zone of small sized marginal peripheral plates, also arranged in diagonal rows, consisting each of about six plates. The latter vary in size and form from small sized plates, laterally extended, to those of much smaller size, vertically elongated, like the vertical scales of the cup of an acorn. The latter fit snugly against the bryozoan surface upon which they rest.

Although only the posterior half of the specimen is preserved it presents the characteristic features of this half in a very satisfactory manner. The reversed curvature of the right posterior ray will distinguish this species from any other hitherto described.

38. The Thecal Plates of Cystaster and Hemicystites

In *Hemicystites stellatus*, Hall (pl. VI, figs. 6A, B), the interambulacral and marginal plates are imbricating. In *Cystaster granulatus*, Hall (pl. VI, figs. 5A–D) the theca consists of a mosaic of minute polygonal plates, distinctly defined but irregularly arranged. These plates ought to show distinctly in specimens magnified to the extent of figure 5A on plate VI, and should show even on the originals of figures 5B and C, if well preserved and thoroughly cleaned. In a specimen of *cystaster granulatus*, 7.5 mm. in width, the diameter of the thecal plates varied between one-fourth and one-third of a millimeter in the interambulacral areas, and between one-fourth and one-fifth of a millimeter on the lower half of the thecal sac. The specimen appears to have been attached at the base.

In *Cystaster* there is no indication of a peripheral ring. In *Hemicystites carnensis*, however, which is only an early form of *Hemicystites stellatus*, the weathered surface (lower part of fig. 2A on pl. III) clearly indicates the presence of large, nearly horizontal plates along the margin which represent the beginning of a peripheral ring; and in those specimens of *Hemicystites* which have the peripheral border extended, the smaller marginal plates are seen to be already differentiated.

On the theory that the *Agelacrinidae* represent forms derived from some cystid source, *Cystaster* evidently presents the most primitive form, as pointed out by Bather. Judging from figure 5D on plate VI, the form was only beginning to assume a sessile habit. *Hemicystites*, on the contrary, shows this sessile habit fully developed. Both forms appear closely related. Squamose imbricating plates are unknown among the true cystids; they can be regarded only as later developments from a primitive stock with a mosaic of polygonal, non-imbricating plates. Imbrication was due to dislocation in consequence of the species taking on a sessile habit. It probably originated at different times and in different lines of descent. Hence, the intimate relationship of *Hemicystites* to *Cystaster*, of *Streptaster* to such forms as *Agelacrinus pileus* (see fig. 1, on pl. II), and of *Agelacrinites* (fig. 3 on pl. VI) to *Lepidodiscus* (fig. 2A on pl. VI).

39. **Hemicystites carnensis,** sp. nov.

(*Plate III, Figs. 2 A, B*)

Two specimens of *Hemicystites* were found 20 feet above the level of the Ohio River on the creek flowing through Carntown, in the northeastern edge of Pendleton County, Kentucky. They occurred on the same rock fragment at the *Strophemena vicina* horizon, in strata containing *Platystrophia colbiensis*, a variety of *Plectambonites sericea, Dalmanella bassleri, Callopora multitabulata, Prasopora simulatrix, Prasopora falesi, Eridotrypa mutabilis*, and *Eridotrypa trentonensis*. The horizon belongs apparently to the top of the strata just beneath the Brannon siliceous limestone as exposed in central Kentucky, near Frankfort.

At Frankfort, a fine grained, siliceous limestone occurs about 50 or 60 feet below the top of the upper or Benson division of the Paris bed. This limestone, called the Brannon member, is of great paleontological interest. In and just beneath this layer are found *Strophomena vicina, Dinorthis ulrichi*, and *Stromatocerium pustulosum*, species found also at a higher horizon, in the Cornishville layer. This is the horizon also for *Brachiospongia*, various species of *Pattersonia*, the form described as *Chirospongia wenti*, and other sponges not known from any other horizons. The immediately underlying strata are included by Ulrich in the Wilmore, while Miller, in his original description of the term, did not draw the line limiting the top of the Wilmore until at least 40 feet lower, where *Dalmanella bassleri* ceases to be abundant. It is to the upper part of the Wilmore, as defined by Ulrich, that the *Strophomena vicina* horizon at Carntown is assigned.

The chief interest in *Hemicystites carnensis* is due to the fact that hitherto only two species of this genus were known: *Hemicystites parasiticus* from the Rochester shale at Lockport, New York, and *Hemicystites stellatus*, from the Fairmount division of the Maysville, at Cincinnati, Ohio. *Hemicystites carnensis* brings the origin of this genus down to a much earlier horizon, and places the genus among those of long duration.

Two specimens, discoidal, almost circular, faintly pentagonal, 7 mm. in diameter. The theca rises abruptly at the side for a distance not exceeding two-thirds of a millimeter. Rays prominent, rising about half a millimeter above the general surface of

the theca; subclavate in outline, with the greatest width, 1 mm., not at mid-length, but about one-third of the length of the ray from the end. This sub-clavate outline is noticeable especially in the case of the anterior ray, opposite the anal area. The posterior rays, on each side of the posterior interambulacral area, branch off not from the center of the theca but from near the base of the lateral rays, on their posterior sides, thus producing wider interambulacral spaces between the proximal ends of the posterior rays than between any of the other rays. Only the lateral covering plates are visible along the rays; nine or ten on each side of the anterior ray, seven or eight on each side of the lateral rays, and eight on each side of the posterior rays. These covering plates are slightly imbricated and their tips alternate along the median line of the rays. Interambulacral plates about as numerous as in *Hemicystites stellatus*. Anus nearer the central part of the posterior area than indicated in the published figures of that species. Upper part of the margin strongly reënforced by large flat plates, the lower margins of which slope gently toward the center, only their upper edges being exposed exteriorly.

On comparing these specimens with *Hemicystites stellatus*, little is found to distinguish them. Compared with the type of that species, the rays are narrower and less elliptical, and the interambulacral areas are correspondingly wider. The trimerid origin of the rays also appears to be more in evidence, owing to the wider separation between the posterior rays. A wider acquaintance with the range of variation of *Hemicystites stellatus* is likely to decrease, rather than increase, the supposed differences of *H. carnensis*. The number of Fairmount forms represented by closely similar precursors among Trenton species is a matter of interest, and this number is continually increasing.

Description of Several Lepadocystinae

40. The Migration of the Anus of the Glyptocystidae

Bather, in his treatise on the Echinoderma, in 1900, and again in his *Caradocian Cystidea from Girvan*, Figure 45, in 1913, determined the probable path of the gut along the inner wall of the theca in the primitive *Glyptocystidae* by noting where the gut pore-rhombs failed to appear in any known species. The second figure is re-

produced on this page as Figure 2. In *Lepadocystis,* from the upper Richmond of Indiana, the gut apparently has been raised sufficiently to cause the disappearance of the pore-rhombs on the middle parts of plates 12, 11, 10, and 14; also on the lower parts of plates 10 and 14 and on the adjoining upper parts of plates 8 and 9. This lifting of the gut was accompanied both by a lifting of the anus and also by a shifting this anus toward the right. The anus was lifted from between the second and third row of plates to a position within the third row, pushing plate 13 upward to a position between plates 18 and 19, and crowding plates 18 and 17 toward the left, altering their primitive pentagonal outline to

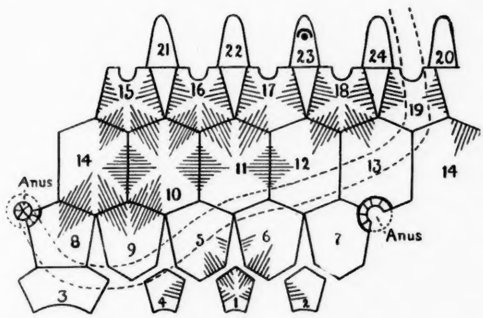


Fig. 2. The actual distribution of all pore-rhombs known with certainty in the Glyptocystidae, showing how a space is left clear where the gut may be supposed to have pressed against the thecal wall. Copied from Bather, in Caradocian Cystidea from Girvan, 1913, page 437.

a more quadratic form. The migration of the anus toward the right appears to be connected with the dextral curvature of the gut within the visceral cavity. At any rate, there does not seem to be any cystid in which the anus may be supposed to have travelled toward the left.

In *Brockocystis,* from the Silurian of Ontario, the anal area occupies a position similar to that of *Lepadocystis,* but it is larger, and has not thrust plate 13 as far upward, so that this plate does not come in contact with the sides of plates 18 and 19 but only with their lower margins. The absence of the pore-rhomb on plates 11–17 suggests a local upward flecture of the gut in this area.

41. **Lepadocystis,** Carpenter, generic characteristics

Lepadocystinae, with oval theca composed of plates arranged as follows:

Basal row, with plates 4, 1, 2, 3.

Second row, with plates 5, 6, 7, 8, 9.

Third row, with plates 10, 11, 12, and 14. Plate 13 has been elevated sufficiently to be chiefly in the fourth row.

Fourth row, with plates 16, 17, 18, 19, and 15. Also most of plate 13.

Fifth row, with plates 22, 23, 24, 20 and 21.

Column obliquely attached at the base, with anal area on that side of the theca which has the longest curvature.

Anal area prominent, between plates 7, 8, 13 and 14.

Pectinirhombs on plates 1–5, 10–15, 11–17, 12–18, and 14–15, with more or less discrete areas of a lunate form, usually deeply impressed on the convex margin, and crossed by rather numerous dichopores.

Ambulacra five, reclining upon the surface of the theca and terminating usually at, or slightly beyond, the middle of plates 15, 16, 17, 18, and 19.

Genotype, *Lepocrinites moorei,* Meek.

The generic term *Lepadocystis* was proposed by Carpenter, in 1894, in vol. 24 of the *Journal of the Linnean Society,* Zoology, on p. 10, in the following words:

Another interesting and geologically earlier form is *Lepocrinites* (*Lepadocrinus*) *Moorei* of Meek, from the Cincinnati group of Indiana, which differs from *L. Gebhardi* in having five ambulacra and a pore-rhomb on plates 10–15, in addition to those on 1–5, 12–13, and 14–15. I am inclined to regard these characters as of generic value, and would propose therefore to distinguish Meek's species by the name of *Lepadocystis.*

To this list of pore-rhombs, as given by Carpenter, should be added that on plates 11–17, as already stated above. The latter had escaped the attention of Meek, owing to the imperfect cleaning of this part of the type specimen.

The anus has been shifted upward and toward the right from its archetypal position between plates 7, 8, and 13, so as to come in contact also with plate 14. In this process, plates 7 and 8 have

become elongated vertically, and plate 13 has been lifted until in contact with the sides of plates 18 and 19, instead of touching them only at their lateral bases.

42. **Lepadocystis moorei,** Meek

(*Plate 5, Figs. 1 A, B, C, D*)

The type of *Lepadocrinites moorei,* Meek, is preserved in the Museum of Earlham College, at Richmond, Indiana. It was found by H. C. Balls, a student at the college, and submitted by Prof. Joseph Moore to Meek. Through the courtesy of Prof. A. D. Hole, I was permitted to examine this type.

The following is an attempt at an independent analysis of the plate system of the type, which is intended to show where the

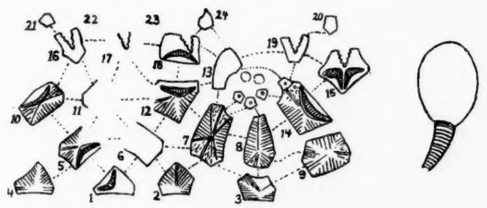


Fig. 3. Diagram of type of *Lepadocystis moorei.* Of plate 17, only the path of the ray is indicated. The natural size of the specimen is indicated by an outline drawing at the right of the diagram. Type preserved at Earlham College, Richmond, Indiana.

details are clearly defined and where they are imperfectly exhibited by the type specimen. This diagram differs but slightly from that presented by Bather in his volume on the Echinoderma, forming Part III of Lancaster's *Treatise on Zoology,* published in 1900.

In this diagram, the character of the surface ornamentation, consisting chiefly of parallel lines radiating in different directions, is indicated, wherever preserved. The ornamentation of plate 13, and of plates 15 to 19, probably was very faint or practically absent. The outlines of plates 11 and 17, and those of the adjacent parts of plates 5, 6, and 12 are so poorly defined that they can not be indicated with exactness. The surface ornamentation of

plates 11–17 was detected only after their presence had been discovered on other specimens on which the surface of these plates was well preserved. A small fragment, probably belonging to plate 13, is drawn in this analysis as though a part of plate 14. This is the fragment drawn by Meek, in his diagram of this specimen, printed on one of the pages interleaved between the index and the numbered plates, at the close of vol. i, of the *Paleontology of Ohio*, in 1873, as though it were a fifth plate in contact with the anal area.

The anal area is composed of two circles of plates, of which the type preserves only three plates belonging to the lower part of the outer circle. The two plates in contact with plate 7 are pentagonal and bear a central tubercle, as described by Meek. A third plate, of a similar character, is in contact with plate 14. Judging from other specimens, the so-called central tubercle, on each of the three lower plates of the anal area may be regarded merely as a continuation of the parallel line ornamentation belonging to the top of plates 7 and 8. From other specimens it is known that the plates forming the top and upper left hand sides of the outer circlet of plates, in the anal area, are of much smaller size than the lower plates, thus reducing the width of the upper part of the outer circlet. The two plates indicated in the upper part of the anal circle therefore are incorrect, and should be replaced by a row of much smaller plates.

The ambulacral arms are clearly outlined. Those parts of the thecal plates upon which they rest are flattened, but not indented or depressed. The arms or ambulacra are longer, more linear, and narrower at their proximal extremities than indicated by Meek's Figure, 4c. Ambulacral plates with facets for attachment of the brachioles at alternate sutures of the ambulacral plates. At these areas of attachment the two adjacent plates form a single rounded low knob, projecting beyond the lateral contour of that part of the plates which intervenes between the points of attachment for the brachioles. The side of each knob is impressed by a single facet. Ambulacralia present but not clearly defined.

In the museum at Earlham College, there is a second specimen of *Lepadocystis*, apparently from the same locality and horizon as the type of *Lepadocystis moorei*—namely, from the Whitewater member of the Richmond, at Richmond, Indiana. It differs in its smaller size, and in the surface ornamentation being more

stellate, probably owing to the retention of only the stronger, central ones among the parallel lines characterizing the type of the species. The character of this stellate ornamentation is indicated in the following analysis of the plate system.

The stellate lines radiate from the center of the plates to their outlines, chiefly to the middle of the sides, but, in part, also to some of the angles of these plates. This stellate ornamentation appears to be characteristic of small sized specimens and may indicate the presence of a distinct variety of this species. For the present it is regarded merely as indicating immaturity.

The most interesting feature of this smaller specimen is the excellent preservation of the surface and of the outline of those plates which, in the type of *Lepadocystis moorei*, were scarcely decipherable. The pectinirhomb on plates 11–17 is well preserved, although distinctly smaller than those on plates 1–5,

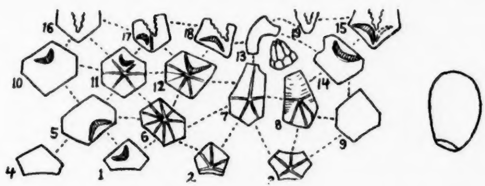


Fig. 4. Diagram of *Lepadocystis moorei*. The natural size of the specimen is indicated by an outline drawing at the right of the diagram. Museum of Earlham College, Richmond, Indiana.

10–15, 12–18, and 14–15. The anal area is surrounded by plates 7, 8, 13, and 14, excluding 19 from any contact with this area. The plates of the anal area are arranged in two circles, of which the outer circle consists of small polygonal plates. Only a part of these plates, those forming the lower and lower right hand part of the outer circle, are exposed. The smaller plates, completing the remainder of the circle, where it is narrower, are not seen. The central circle consists of more triangular plates, evidently meeting at the center in the form of a prominent cone, but, owing to the strong inclination of this cone toward the oral end of the specimen, only three of these triangular plates are well exposed, and the total number can not be determined. In other specimens they are not as narrow as here indicated. The outlines of plates 20 to 24 cannot be distinguished with certainty.

A third specimen of *Lepadocystis*, also in the Museum of Earlham College, is contained in a rock fragment containing large numbers of *Zygospira modesta* and some branching bryozoan, apparently *Bythopora delicatula*. These forms indicate the Richmond origin of the cystids, and eventually may lead to a rediscovery of the exact horizon.

A fourth specimen of *Lepadocystis*, belonging to that part of the Dyer Collection which was not sold to Harvard University, has been acquired recently by Miami University, and was obligingly loaned to me by Professors S. R. Williams, and W. H. Shideler. It was obtained from the upper part of the Richmond, at Richmond, in Indiana. This specimen also presents the radiate surface ornamentation already noted in the smaller sized specimen here

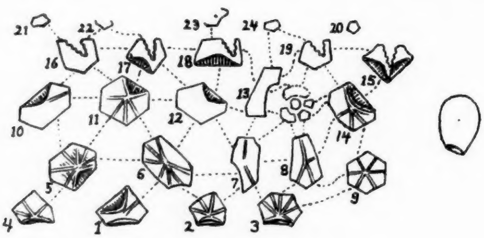


Fig. 5. Diagram of *Lepadocystis moorei*. The natural size of the specimen is indicated by an outline drawing at the right of the diagram. Museum of Miami University, Oxford, Ohio.

described from the Earlham College collection. The character of this ornamentation is indicated in the following analysis of the plate system.

The pectinirhomb on plates 11–17 again is well defined. The outline of plate 7 certainly is aberrant, and should be more like that illustrated in the two preceding diagrams. Possibly there is a break in the plate near its lower left hand margin, causing a misinterpretation of its outline here. Only the larger plates of the outer circle forming the anal area can be distinguished. The largest of these is in contact with plates 8, 7, and 13, and evidently is the anchylosed representative of two of the plates figured in the type of the species. The upper part of the outer anal circle is known, from other specimens, to have been occupied by a row of

very small plates. The space belonging to the inner circle is occupied by a circular mass, half a millimeter in diameter, within which it is impossible to distinguish any individual plates. Possibly this part of the anus was more or less retractile. It is very probable that the outline between plates 13 and 19 was drawn incorrectly in this diagram. Judging from other specimens, plate 19 never should be in contact with the anal area, in this species, and the lower left hand part of plate 19, as illustrated in this diagram, unquestionably belongs to the adjacent part of plate 13. The line of separation between plates 19 and 13 should be drawn along the left border of the ambulacrum or subvective system. Judging from other specimens, the difficulty of distinguishing the outline between plates 19 and 13 arises from the fact that this outline frequently is covered by the left margin of the ambulacrum, which does not cross the middle of plate 19, as here drawn in the diagrams, but traverses the left half or left two-thirds of the plate instead. In each of the diagrams here presented the effort was made to interprete the specimen on the basis of what the specimen actually appeared to suggest, irrespective of every other specimen. In the case of the present diagram, the supposed outline between plates 19 and 13 probably is due to a crack crossing plate 13, and the covering up of the real line of separation by the ambulacrum crossing the left part of plate 19. Owing to the difficulty of distinguishing plates 20 to 24, the outlines here presented have little value. Stereom-folds in pectinirhombs 1–5, 12–18, 14–15, 10–15, about eleven; in pectinirhombs 11–17, about seven. These numbers disagree with the number of stereom-folds found in specimens of larger size, which resemble the type in having a parallel-line ornamentation, instead of a stellate plate ornamentation.

That part of the Dyer Collection acquired by Miami University contains also another specimen of *Lepadocystis,* with the theca broken across so as to expose the interior of one side. Interior views of pectinirhombs 1–5, and 11–17 are presented. These pectinirhombs project angularly into the interior cavity, the stereom-folds passing uninterrupted from plate to plate, and are not discrete, as on exterior view. The stereom-folds on pectinirhomb 1–5 number about eleven, and those on pectinirhomb 11–17 number seven. Both an exterior view of the column and of its area of attachment on the interior of the theca are presented. The column is rather large at its area of attachment, and tapers

rapidly. It probably was short and did not serve as a means of attachment in mature specimens.

In the Walker Museum of Chicago University there are three specimens of *Lepadocystis moorei* belonging to the Faber Collection, and numbered 9961.

Of these, one specimen, A, is defective at the base, but otherwise is remarkably well preserved (plate V, Fig. 1A, C). The ornamentation is of the parallel line character, as in the type, but certain of the lines are slightly stronger, and it is evident that by the accentuation of the stronger lines the stellate ornamentation of the smaller specimens could be derived. Of the first row of plates, only plate 1 is preserved entire. The basal parts of plates 7 and 8 are missing. The ambulacrum, which crosses the

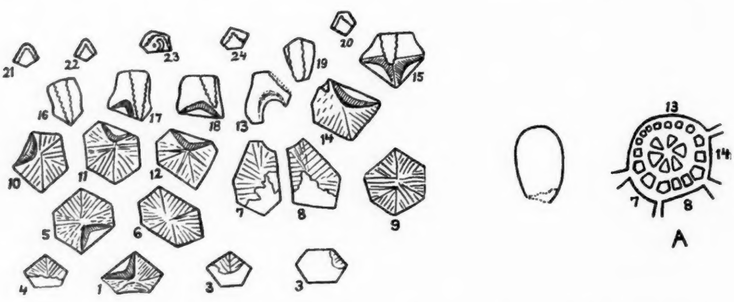


Fig. 6. Diagram of *Lepadocystis moorei*. The natural size of the specimen is indicated by an outline at the right of the diagram. *A*, diagram of anal area, in contact with plates 7, 8, 13 and 14. Specimen No. 9961A, Faber Collection, Chicago University.

left side of plate 19, slightly overlaps the adjacent edge of plate 13 and intrudes upon the upper left hand corner of plate 14, at the left of the pectinirhomb 14–15. All of the ambulacra are remarkable for their length. That on plate 16 reaches the extreme lower angle of the plate. That on 17, borders the upper right hand side of the pectinirhomb and does not quite reach the lower angle. That on plate 18 terminates in a similar position. That on 15 overlaps the tips of the adjacent angles of pectinirhombs 14–15 and 10–15. Only the lower outlines of plates 20, 21, 22, and part of 23 are faintly perceptible.

The ambulacra appear to consist of two series of plates, more or less alternating, which rest upon the theca. On plate 18, several of these ambulacral plates have dropped off, leaving slightly concave depressions. The lateral covering plates of the subvective grooves are well preserved at the proximal ends of several of the ambulacra, notably between deltoids 20 and 21, where these covering plates are seen to meet along the median line at an acute angle. Covering plates are seen also between deltoids 21 and 22 and between 20 and 23. In order to make the structure of the tegmen agree with the theory of an early trimerous structure, among the Echinoderma, leading subsequently to a pseudo-pentamerism, it is necessary, in the present species, to regard the left primary branch of the subvective system, between deltoids 21 and 23, as much abbreviated, compared with the right primary branch, between deltoids 20 and 23. From these primary branches, two secondary branches originate on the right, and two on the left, by bifurcation. The anterior primary branch does not lie directly opposite the posterior deltoid, 23, but is directed slightly to the right. (See text Fig. 7A on page 466 in this BULLETIN.) The lateral covering plates are oblong in form and very minutely striated in a vertical direction. There is no differentiation of these plates at the center so as to form a district oral group.

Stereom-folds in pectinirhombs 1–5, sixteen; in pectinirhomb 12–18, twenty; in pectinirhomb 14–15, nineteen; in pectinirhomb 10–15, sixteen; and in pectinirhomb 11–17, twelve.

The anal area (Fig. 6A) presents details not seen in preceding specimens. In contact with plate 8 are four small plates, of which the two extreme are in contact also with plates 7 and 14, respectively. Another plate of about the same size is in contact with the middle part of the anal outline of plate 7, and two additional plates are in contact with plate 14. All of the plates in contact with plate 13 are of smaller size than any of the other plates belonging to the outer circle in the anal area, especially toward the upper left hand side of this area, but the details here cannot be definitely determined. From the left side of the moderate depression within this outer circle of plates, a pyramid of small triangular plates, meeting at the center, projects, but their number is not known definitely. Judging from other specimens, the anal area has not yet been accurately worked out, or else it varies more or less in structure in different specimens.

Another specimen from the Faber Collection, 9951B (plate V, Fig. 1, B, D) presents all of the plates, and has the parallel line ornamentation of the type specimen. This ornamentation has been omitted in the following diagram.

All of the plates belonging to the first three rows are distinctly outlined, excepting plates 13 and 14, and, of these, plate 13 has been pushed up until it belongs practically to the fourth row, as already noted in the description of the genus. The right hand margin of plate 13 is concealed by the ambulacrum which traverses the left three-fourths of plate 19 and reaches a point on plate 14 opposite the middle of the anal area. The last two left hand brachioles of this ambulacrum are preserved. They consist of two series of alternating plates, about five or six in each series. Judging from other specimens, the brachioles near the proximal end of the ambulacra

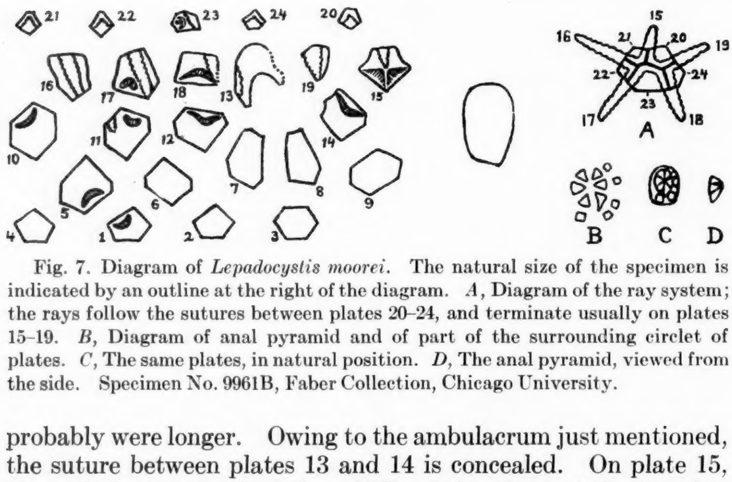


Fig. 7. Diagram of *Lepadocystis moorei*. The natural size of the specimen is indicated by an outline at the right of the diagram. *A*, Diagram of the ray system; the rays follow the sutures between plates 20–24, and terminate usually on plates 15–19. *B*, Diagram of anal pyramid and of part of the surrounding circlet of plates. *C*, The same plates, in natural position. *D*, The anal pyramid, viewed from the side. Specimen No. 9961B, Faber Collection, Chicago University.

probably were longer. Owing to the ambulacrum just mentioned, the suture between plates 13 and 14 is concealed. On plate 15, the ambulacrum reached the middle of the plate, at the junction of the two adjacent angles of the pectinirhombs. This is the anterior ambulacrum, and is always the shortest. On plate 16, the ambulacrum crosses only slightly to the right of the middle of the plate and passes a short distance beyond the suture between plates 16 and 17. On plate 17, the ambulacrum crosses the entire length of the plate, grazing the upper right hand margin of the pectinirhomb, and at least one of the ambulacral plates reached

the adjacent angle of plate 12. Several of the ambulacral plates have dropped off from the theca. Of the ambulacrum on plate 18, only the proximal plates remain. The others have dropped off from the theca, but the flattened area on the latter indicates that the right side of this ambulacrum formerly covered the suture between plates 18 and 13, and that the tip of this ambulacrum reached at least the lower right hand angle of plate 18. From the center of the tegmen, the anterior ambulacrum, on plate 15, extends 3.5 mm.; the right anterior ambulacrum, on plate 16, 6 mm.; the right posterior ambulacrum, on plate 17, 5.5 mm.; the left posterior ambulacrum, on plate 18, 6.5 mm.; and the left anterior ambulacrum, on plate 19, 7 mm. Judging from the elevations at the attachments for the brachioles, the number of brachioles on each side of the anterior ambulacrum were about three or four; on each side of the right anterior ambulacrum, about five or six; on each side of the left posterior ambulacrum, about six or seven; and on each side of the left anterior ambulacrum, also about six or seven. The right posterior ambulacrum is not sufficiently preserved, but judging from its length it probably had five or six brachioles on each side.

The outlines of the deltoids, or plates belonging to the fifth row, are more readily detected in this specimen than in any other, and the result is indicated in the accompanying diagram.

Stereom-folds in pectinirhomb 1–5, unknown; in pectinirhomb 12–18, nineteen; in pectinirhomb 14–15, twenty-one; in pectinirhomb 10–15, about sixteen; and in pectinirhomb on plates 11–17 about ten or eleven.

At the lateral ends of the pectinirhombs, the stereom-folds often are continuous across the suture lines, exteriorly as well as interiorly, but along the middle of the rhomb there is a lens-shaped area, including parts of both plates along the suture lines, in which the folds are not visible. From this lens-shaped area, the stereom-folds on plates 10, 11, 12, and 14 slope downward, and on plate 5 slope upward, both the upper and lower lip of the fold area being sharply defined by a raised border. On plates 15, 17, and 18 the stereom-folds slope upward, and here only the upper lip is sharply defined. In a similar manner, the stereom-folds on plate 1 slope downward and are strongly defined only along the lower lip.

The anal area presents evidence of at least two circles of plates, of which the interior one forms the conical pyramid. Apparently

at least six plates take part in this cone. The outer circle consists of larger plates where in contact with plates 7 and 8, of medium sized plates where in contact with plate 14, and of small plates where in contact with plate 13. The details are more or less obscured.

A third specimen in the Faber Collection, 9961C, is badly weathered, but for that very reason presents an excellent view of the outlines of plate 19, all of the ambulacral plates having dropped off. The suture between 13 and 14 also is well exposed, and there is no doubt as to the exclusion of plate 19 from contact with the anal area. Plate 19 is never in contact with plate 18. Some of the deltoids are very distinctly outlined along parts of their margins. A brachiole attached to one of the proximal facets of the ambulacrum crossing plate 16 has a length of more than 3 mm. The most interesting part, however, is the anal area, which again presents an outer and inner circle of plates. The inner circle forms the conical pyramid, and apparently consists of nine plates, although the number may have been only seven. The outer circle has the largest anal plates along plates 7 and 8, with medium sized plates along plate 14 and the immediately adjacent part of plate 13. The remaining anal plates, along plate 13, form a very narrow row of very small plates. Perhaps the total number of anal plates in contact with plate 13 is as great as fifteen or sixteen. From this the very small size of th smallest plates may be inferred. The circular area of attachment of the column has an interior diameter of 2.3 mm., and an exterior diameter of 3.2 mm.

43. **Brockocystis,** Gen. nov.

This genus is very closely related to *Lepadocystis*, but differs in the following particulars:

There is no pectinirhomb on plates 11–17. Plate 19 is in direct contact with plate 18, at least along the upper lateral margins of the two plates. Plate 13 has not been raised sufficiently to separate plates 18 and 19, but comes in contact only with their lower lateral outlines. Anal area large. The ambulacral or subvective system is much more restricted, the ambulacra extending only short distances over plates 16 and 17, and not reaching the base of plates 18 and 19. The number of brachiole facets is very small, and although the brachioles are missing it may be assumed

that these were correspondingly stout. The ornamentation is entirely different, consisting of an irregular network of interlacing raised lines.

GENOTYPE, APIOCYSTITES TECUMSETHI, BILLINGS

Genus named in honor of the distinguished head of the Geological Survey of Canada, Dr. R. W. Brock.

44. **Brockocystis tecumsethi,** Billings

(Plate V, Figs. 2 A, B, C)

Apiocystites? Tecumseth, Billings. Catalogues of the Silurian fossils of the Island of Anticosti, with descriptions of some new genera and species. Geological Survey of Canada. Montreal, p. 91. 1886.

The original description of this species follows:

This species is proposed for a Cystidean collected by Prof. R. Bell and H. C. Vennor, on Manitoulin Island in 1865. Only detached plates and fragments of the column were found. Most of the plates have a large hemispherical protuberance which occupies all of the plate, except a narrow flat border all around. The rhombs consist of two separated triangular spaces, their bases separated as in *A. elegans*, Hall. The column has from three to four lines in length at the point of attachment, encased in an ovoid mass which is either a secretion of the column itself, or a parasitic zoophyte, or, perhaps, a sponge. The surface of this part, as well as that of the tumid part of the plates, is covered with small polygonal pits. Near South Bay, Manitoulin Island; Prof. R. Bell, H. G. Vennor.

The detached plates of the type series were shown me in 1904 by Mr. Whiteaves. Similar plates are very common not only on the surface of the high hill southwest of Manitouaning but also along the road between Gore Bay and Kagawong, at a crossing over a wet weather stream, exposing a rocky bottom, about half a mile east of Ice Lake. As remarked by Schuchert (*On Siluric and Devonic Cystidea and Camarocrinus*, 1904, p. 212): "Until the theca of A.(?) tecumseth is known, this can not be regarded as an established species." Fortunately, an excellently preserved specimen was found by the writer near the top of the Cataract limestone at the locality east of Ice Lake. It forms No. 8447 in the collections, of the Canadian Geological Survey, in the Victoria

Memorial Museum, at Ottawa, and forms the basis of the following very full description.

Plates arranged as in the following diagram.

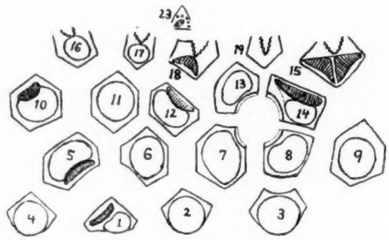


Fig. 8. Diagram of *Brockocystis tecumsethi*, Billings. The outlines of plates 20-24 could not be determined with accuracy. The outlines of the hemispherical protuberances are indicated. Specimen No. 8447, in the collections of the Geological Survey of Canada.

The plates of the fifth row are practically concealed under the plates belonging to the ambulacral or subvective system. There apparently is a trace of the outline between deltoid 23 and plate 18, but the remainder of the outline of plate 23 is not known and no deductions must be drawn from the outline of this plate in the diagram, which represents merely the space between the overlapping ambulacra. The plates bearing the large hemispherical protuberances are indicated in the diagram. Those on plates 1 and 13 are small. Those on plates 2, 3, 4, 14, 16, and 17 are of medium size. The remainder are large. No protuberances occur on plates 18, 19, or 15, excepting the triangular supports for the ambulacra. On these three plates, also, the reticulate ornamentation is faint or obsolete.

Pectinirhombs more or less discrete along the suture lines separating the two plates forming the rhomb. The lower boundary of the rhomb on plates 12, 14, and 10 is strongly defined by a vertical wall formed by the adjacent part of the hemispherical protuberances on these plates. The upper part of the stereom-fold area on the same plates also is sharply defined, but only by a sharp striation. The boundaries of the fold areas on plates 15 and 18 are distinct, but not defined by conspicuously elevated striae or walls. The pectinirhomb on plates 1–5 is strongly defined by a vertical wall along its upper outline on plate 5, it is strongly

defined, but by much less conspicuously raised borders, on both sides of suture separating plates 1 and 5, and is inconspicuously bordered along its lower margin on plate 1. Stereom-folds on plate 5, about eighteen; in pectinirhomb 12–18, about twenty-three; in pectinirhomb 14–15, about twenty-three; and in pectinirhomb 10–15, about fourteen or fifteen.

Anal area circular, about 5 mm. wide and perhaps a little longer. Anal plates missing, but evidently supported on a flange along the lower part of the opening formed by plates 7, 8, 13, and 14.

At the base of the theca, the protuberances on plates 1, 2, 3 and 4 project below the level of attachment of the column. This is true especially of plates 2, 3, and 4. The outer diameter of the area of attachment is 5.3 mm. and the inner diameter is about 3.2 mm.

Column very short, the columnals fused together and surrounded by a sclerodermous mass having a pyriform outline and ornamented at the surface with the same pitted and reticulated structure as the plates of the theca. The length and width of the fused column together with the surrounding sclerodermous material usually is less than 10 mm. At the lower end it is narrowed to a flattened surface, suggesting an early statozoic stage. The diameter of this flattened surface usually varies from 2 to 3 mm., but sometimes equals nearly 4 mm. Through the center of the sclerodermous mass there passes a vertical, funnel-shaped opening, interpreted as representing the column. The first columnal evidently was wide, corresponding to the broad area of attachment at the base of the theca. The second columnal was conspicuously smaller, usually not exceeding 3 mm. in width, if the structure has been interpreted correctly. The third columnal was still smaller, varying from 1.5 to 2 mm. in diameter. Beginning with the third, the remaining columnals form the less rapidly tapering or more tubular part of the "funnel." In one specimen this funnel diminishes in width from 2 to 0.7 mm. in a length of 7 mm., including 15 columnals. Of these columnals, the first 8 occupied a length of 4 mm. and the next 7 of 3 mm. Each columnal tends to be surrounded by two transverse ridges separated by a transverse groove. That part of the sclerodermous covering which lines the column, and also that part which forms the pitted and reticulated surface, is solid. The intervening part of the sclerodermous mass often is less solid,

and in one specimen, this space was transversed by thin circular sheets of sclerodermous material, one sheet for each columnal, extending from the column diagonally upward toward the pitted surface. These thin annular sheets are fluted radiately, the fluting possibly having some connection with the reticulated surface markings. Adult animal probably eleutherozoic.

Ambulacral or subvective system coarse, confined to the extreme top of the theca. Ambulacral grooves strong, about a millimeter wide at their proximal ends, uniting at the center of the tegmen in an oral orifice nearly 2 mm. wide and a little over 1 mm. in diameter in an antero-posterior direction. This orifice descends into the theca, but probably was entirely concealed by covering plates, as in the closely related genus, *Lepadocystis*. No trace of covering plates, however, remains.

The trimerous origin of the ambulacral system is clearly defined. The anterior ambulacrum is directed toward the right of a line drawn perpendicular to the line connecting the terminations of the lateral primary ambulacral grooves. It extends 4.5 mm. from center of the tegmen almost to the adjacent proximal angles of the pectinirhombs on plate 15. The lateral primary grooves bifurcate about 1 mm. from the oral passage or 2 mm. from the center of the tegmen. The right anterior ambulacrum terminates on plate 16, about 6 mm. from the center of the tegmen, and is almost a direct continuation of the right primary division of the ambulacral system. The right posterior ambulacrum curves strongly backward and toward the left, terminating on plate 17, about 5.5 mm. from the center of the tegmen. The left posterior ambulacrum is directed diagonally backward to plate 18, terminating about 7 mm. from the center of the tegmen. The right anterior ambulacrum curves forward to plate 19, and terminates 7 mm. from the center of the tegmen. All of the ambulacra are broad at their proximal ends and bluntly triangular in form. In each case one or more ambulacral plates are missing. Judging from those remaining, the number of brachioles on each side of each arm usually was two, but may in some cases have equalled three, or may even have been reduced to one on one side. The proximal one of these brachioles, judging from the facets, probably was coarse, and the distal brachiole, at least smaller.

43. **Brockocystis clintonensis,** Parks

(*Lepadocystis clintonensis, Parks. American Journal Science, vol. XXIX, 1910, p. 404, Figs. 1, 2*)

This species unquestionably is congeneric with *Brockocystis tecumsethi.* It not only has the same diagrammatic arrangement of the plates but also a closely similar form of ornamentation. The type specimen, No. 372C1, in the Museum of the University of Toronto, is 15 mm. high and 10 mm. wide, while the height of *Br. tecumsethi* is 23 mm. The type of *Br. clintonensis* was found at the Forks of the Credit River, Ontario, in the Cataract formation. The plates are not elevated at the center into large hemispherical protuberances, but follow merely the general convexity of the theca. The column is round and tapers distally. The first ten columnals, at mid-length, show a sharp transverse crest and occupy a length of about 7 mm. Distally, the columnals increase in length, and beyond the tenth columnal the crest becomes less defined and the columnals become barrel-shaped. The seventeenth columnal is 2 mm. long and about 2 mm. wide.

44. **Brockocystis huronensis,** Billings

Apiocystites huronensis, Billings. Catalogues of the Silurian Fossils of Anticosti, 1866, p. 91, fig. 28.

Apiocystites (?) *huronensis,* Schuchert. On Siluric and Devonic Cystidea and Camarocrinus. Smithsonian Miscellaneous Collections, vol. 47, part 2, 1904, p. 212.

The original description is as follows; in this description the numbers of the plates have been added in brackets.

The specimen is partly buried in stone and its generic characters cannot be ascertained. The plates are moderately convex, depressed at the sutures. The rhomb at the base is one-half on a basal plate (plate 1), and one-half on a plate (plate 5) of the second series. In the upper part is another rhomb, one-half of which is on a plate (plate 10) of the third series, and the other apparently on a plate (plate 15) of the fourth. The lower half, however, of the basal rhomb (plate 1), and the upper half of the upper rhomb (plate 15) are not distinctly seen. As no arms are visible, it seems certain that this species is not a true *Apiocystites.* The position of the rhombs also favors this view. The specimen was

found near Cabot's Head, on the shore of Lake Huron. Clinton; or Niagara formation (at present called Cataract formation). A. Murray, Esq.

From the accompanying figure (fig. 28) it is evident that in addition to the plates mentioned, plates 4 and 9 also are present. The column is round, and tapers distally. Only the proximal columnals are present. Reticulate markings are not in evidence on the plates of the theca, but the specimen evidently is more or less weathered. The height of the complete theca probably was about 16.5 mm., agreeing in this respect quite closely with *Brockocystis clintonensis*, Parks, from the same horizon. From the latter species, *Brockocystis huronensis* appears to differ chiefly in its more convex thecal plates. Evidently more material is necessary before *Brockocystis huronensis* can be considered an established species.

Judging from present knowledge, *Brockocystis* is confined to the Cataract formation, while *Lepadocystis* is known only from the upper Richmond.

PLATES

PLATE I

Fig. 1. Agelacrinus holbrooki, James. *A*, Figure of type. *B*, Outline, side view of specimen, showing dome shaped elevation; figures accompanying the description of the species in the Journal of the Cincinnati Society of Natural History, vol. x, p. 25, in 1887. *C*, anal region much enlarged, showing the squamous plates of the margin; the termination of the two posterior rays, Nos. 1 and 5, with both lateral and central covering plates; the anal pyramid, surrounded by small plates; copy of figure published by Clarke in New Agelacrinites, p. 189, in 1901, forming No. 40744, of the U. S. National Museum. *D*, Lateral outline of specimen No. 1004, in the James collection, at Chicago University, regarded as the type of the species although not oriented as in the published figure of the latter; the distal parts of the posterior rays, Nos. 1 and 5, and part of the anal pyramid are preserved in this specimen; the drawing is intended to indicate the slumping of the theca owing to its supposed attachment to a slanting valve of Rafinesquina, the proximal part of the right ray, No. 4, being directed toward the upper part of the slanting surface. *E*, five floor plates from the anterior ray of specimen 1004, the lower three of which are parallel to the peripheral ring, and the upper two belong to the same ray, in a proximal direction; at the base of the drawing, the exposed parts of two covering plates are indicated; at the top, the basal extensions of three covering plates are represented; transverse sections of two of the floor plates are presented. *F*, A lateral covering plate, and lateral view of the same to indicate its curvature, f·om specimen 1004.

Fig. 2. Agelacrinites beecheri, Clarke. Floor plates seen from below. Copied from figure accompanying the original description, in New Agelacrinites, in Bulletin 49, N. Y. St. Mus., on page 195, in 1901. Apparently only long enough for one lateral covering plate on each side of the floor plate. No. 4001-1, plastotype, N. Y. State Museum.

Fig. 3. Agelacrinus faberi, Miller. *A*, lateral view; *B*, view from above; copies of the figures accompanying the original description, in Journal, Cincinnati Soc. Nat. Hist., vol. xvii, on plate 8, in 1894. The type forms No. 8821 in the Faber collection, at Chicago Univ. *C*, floor plates of the type, accompanied by a cross section of the same.

Fig. 4. Agelacrinus warrenensis, James. *A*, natural size; *B*, same specimen enlarged; copies of figures accompanying the original description, in The Paleontologist, No. 7, plate II, in 1883. Regarded as young specimen of Agelacrinus cincinnatiensis, poorly preserved.

Fig. 5. Agelacrinus pileus, Hall. *A*, central part of figure published by Miller and Faber, in Journal of Cincinnati Soc. of Nat. Hist., vol. xv, on plate I, in 1892. On that plate, the proximal part of the anterior ray is directed diagonally downward toward the right. In the figure here presented, this part of the ray is directed upward, and the rays are numbered. A part of the lower surface of the oral face of the theca is illustrated. Remnants of floor plates are seen at the proximal ends of rays 3 and 2. Most of the proximal floor plate forming that part of the rim of the substomial chamber which arches across ray 4, as seen from below, is missing. The proximal floor plates forming that part of the rim arching across rays 5 and 1 are entirely absent. The lateral covering plates with their basal extensions are shown. Also three of the peristomial plates, the two anterior rhomboid plates and the posterior quadrangular plate, with their dovetailing ridges, as seen from below. This specimen forms No. 8825 in the Faber collection, at Chicago University. *B*, Peristomial plates and some of the adjoining plates of specimen No. 1192-2-A, belonging to the American Museum of Natural History. In this drawing *L* represents the left anterior rhomboid peristomial plate; *R*, the corresponding plate on the right side; *P*, the quadrangular plate on the posterior side of the peristomial slit. The basal plates of the rays are numbered so as to indicate the rays to which they belong. The proximal part of the anterior ray is directed toward the left, the position which it usually occupied when the animal rested on an inclined surface. The peristomial slit divided at its left end at plate *Z*, one branch passing between the two plates marked 2, and the other branch between the two plates marked 1. In a similar manner, the slit divided at its right end at plate *Y*. A duct may have opened near the meeting point of plates *P*, 5, and *X*. *X* is merely one of the interambulacral plates. In the case of the anterior ray, No. 3, several of the lateral covering plates are drawn as though they exposed also the basal extensions of these plates, but the latter details were added from the specimen represented by Fig. 5a, on this plate. *C*, one of the lateral covering plates of the specimen represented in Fig. 5A, on this plate, as seen from below, showing two striae at the base, paral el to the length of the ray; also a lateral view of the same, to show its curvature. *D*, lateral view of a covering plate belonging to the opposite side of the ray.

Fig. 6. Agelacrinus cincinnatiensis, Roemer. *A*, lateral covering plate with diagonally directed basal extension, as seen at the angle between two rays, in specimen No. 13266-1-c, in the American Museum of Natural History. *B*, three lateral covering plates, and a lateral view to indicate the curvature of the latter, from specimen No. 1008 *C*, in the James collection, at Chicago University. *C*, two floor plates, showing a narrow longitudinal groove on each side, from a specimen in the Geological Museum of Ohio State University; also a transverse section of the same. *D*, one of the large plates forming the inner band of the peripheral ring, showing the three short vertical ridges near the base of the inner face; from specimen 13266-1-s, of the American Museum of Nat. Hist.; *E*, the edges of several of these plates, as seen from the interior of the theca, showing the location of these vertical ridges in the spaces left between the lateral edges of the adjacent plates, thus giving rigidity to the inner band of the peripheral ring; from specimen 13266-1-r, in the same museum as the last.

Fig. 7. Streptaster septembrachiatus, Miller and Dyer. *A*, view of central part of oral face of theca, as seen from below, including the substomial chamber and the adjacent parts of the rays. The rays are numbered. There appears to be a deep cavity at the posterior border of the substomial chamber, foward of which, as seen from below, there is a quadrangular plate with broad groove ascending it on the left. In the case of the rays, only the floor plates, as seen from below, are indicated. The peristomial plates, as seen from below, are not sufficiently defined to be represented with accuracy. The anus was located close to the substomial chamber, between rays 5 and 1. A part of the surrounding interambulacral area appears to be preserved. *B*, three floor plates as seen from the side, supporting three vertical palisade like lateral covering plates; also an imaginary view of these three floor plates as seen from the top, with facets for the support of two lateral covering plates on each floor plate.

Fig. 8. Thresherodiscus ramosa, Gen. et. sp. nov. Parts of the proximal portions of rays 3, 4 and 5, drawn so as to indicate the usage of certain terms in the accompanying descriptions. The basal parts of the arms are numbered; *f l* indicates the floor plates in the case of the two primary branches of the anterior ray, No. 3; *b* indicates the small bordering interambulacral plates adjoining the floor plates of the anterior ray and the lateral covering plates of one side of the right ray, No. 4; *ia* indicates the location of the large central interambulacral plates, within the zone of much smaller bordering interambulacral plates; *C*, indicates the two rows of lateral covering plates on one of the branches of the right ray, No. 4. The supernumary covering plates along the median line of the ray, between the lateral covering plates, are also indicated in the drawing, without any effort at accuracy of detail, but are not designated by any letter. Only enough is shown in the drawing to illustrate the usage of the terms here indicated.

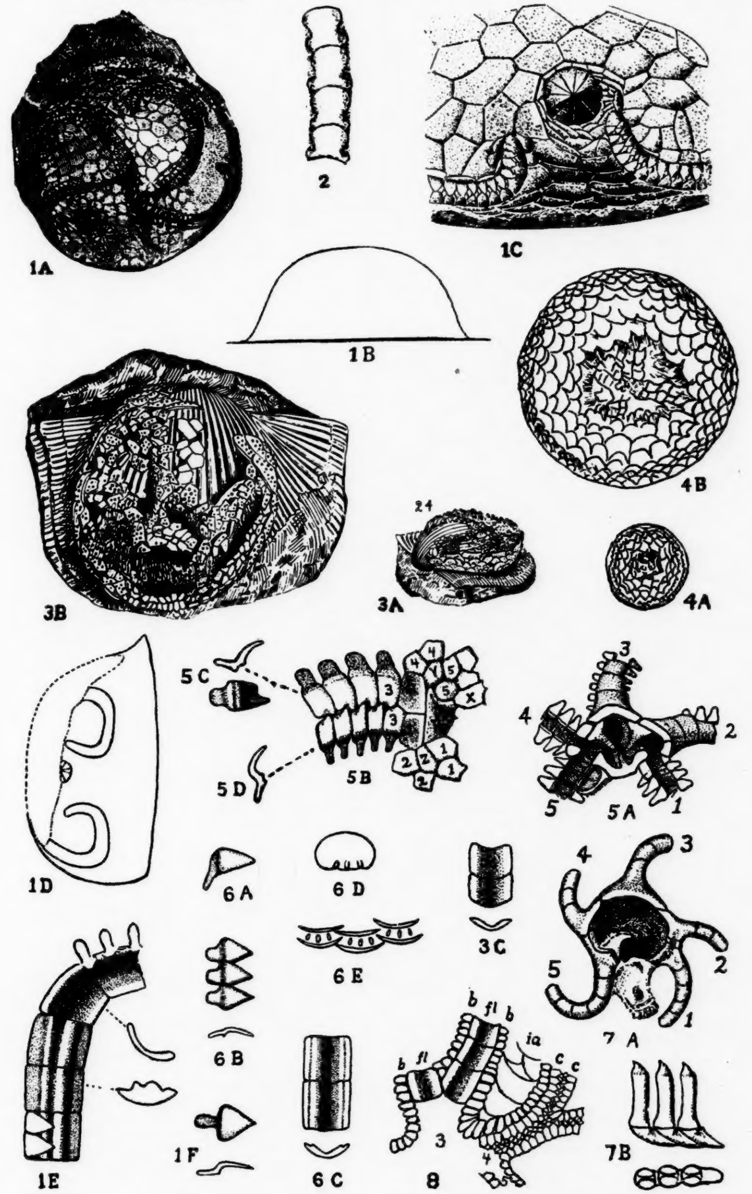

1A
2
1C
1B
3B
4B
3A
4A
1D
5C
5D
5B
5A
6A
6D
3C
7A
1E
6E
6B
1F
6C
8
7B

PLATE II

Fig. 1. Agelacrinus pileus, Hall. The specimen has sagged downward so as to expose the peripheral ring strongly along the upper part of its outline; but, along the lower part of this outline the peripheral ring is almost concealed by the sagging theca. Covering plates with a spinous prolongation on the proximal side. Peristomial plates; and apparently a small opening between plates *P*, 5, and *X* (See diagram 5B on Plate I) are clearly exposed. Several of the plates belonging to the inner band of the peripheral ring are strongly exposed along the upper side of the theca on account of the drag produced by the sagging theca. Specimen No. 13266-1-t, in the American Museum of Natural History, in New York City Enlarged 4 diameters. From Cincinnati, Ohio. Corryville member of Maysville.

Fig. 2. Agelacrinus pileus, Hall. Specimen with surface very minutely pitted, the pits showing in the photograph but not in the engraving. The spinous prolongations along the proximal edges of the covering plates so little in evidence that the tips of the latter, along the median line of the ray, appear like alternating V-shaped terminations. Peristomial plates clearly defined. Contact between plate *X*, and plates *P* and 5 loosened. Anal pyramid apparently consisting of imbricating plates, the tips of the inner plates being exposed. Specimen No. 13268-1-a, in the American Museum of Natural History, in New York City. Enlarged 5 diameters. From Cincinnati, Ohio. Corryville member of Maysville.

Fig. 3. Agelacrinus pileus, Hall. View of lower surface of upper or oral part of theca, showing substomial cavity, with the anterior margin clearly defined. The floor plates of rays 1, 2, and 3, entirely conceal the basal extensions of the covering plates. Specimen No. 13266-1-x, in the American Museum of Natural History, in New York City. Enlarged 4.4 diameters. From Cincinnati, Ohio. Corryville member of Maysville.

Fig. 4. Agelacrinus pileus, Hall View of lower surface of upper or oral part of the theca. This is the speciman figured by Miller and Faber, in the *Journal of the Cincinnati Society of Natural History*, vol. XV, pl. I, fig. 10. The basal extensions of the covering plates are exposed best on rays 1, 2, and 3. The floor plates are seen at the proximal ends of rays 3 and 4; these plates are very thin and the sutures are not well shown. The entire specimen appears far less robust, as seen from the interior, than the specimen represented by figure 3 on this plate. The inner termination of the posterior peristomial plate is well exposed. Specimen No. 8825, Faber Collection, in Walker Museum, at Chicago University. Enlarged 4.5 diameters. From Cincinnati, Ohio. Corryville member of Maysville.

Fig. 5. Lichenocrinus affinis, Miller. Two specimens of the basal attachment disc of some crinoidal body, and the upper surface of the attachment film, as seen after the removal of the plates forming the upper part of this disc. This attachment film is radiately striated. Type, forming specimen No. 8810, in the Faber Collection at Chicago University. Enlarged 4.5 diameters. Probably from upper or Blanchester division of Waynesville, at Lebanon, Ohio.

Fig. 6. Lichenocrinus subaequalis, Foerste. Types, two specimens. Enlarged 3 diameters. From north of Rogers Gap, Kentucky. Rogers Gap member of Cynthiana formation.

PLATE II

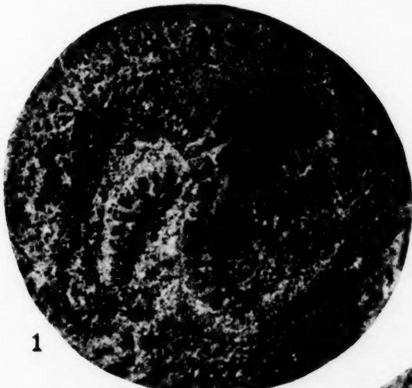
PLATE III

Fig. 1. Agelacrinus vetustus, sp. nov. The granulation probably is due to a thin membrane of Dermatostroma covering the entire animal even before death, but permitting the opening of the ambulacral rays, the peristomial plates, and the anus. From Clays Ferry, 14 miles southeast of Lexington, Kentucky; in the fossiliferous strata between 38 and 69 feet above the massive limestone, near the watering trough on the south side of the Kentucky River. Greendale member of the Cynthiana formation. Magnified 5 diameters.

Fig. 2. Hemicystites carnensis, sp. nov. Two specimens on the same rock fragment, in contact with each other, *A* being located on the right and slightly below *B*, when oriented as in these figures. Both specimens preserve traces of the interambulacral plates in the area on the left of the anterior ray. The covering plates are best preserved in specimen *A*, and this specimen also exposes the nearly horizontal plates belonging to the inner band of the peripheral ring, along the lower margin of the theca. Several hundred yards up the creek from the railroad at Carntown, Kentucky. At the Strophomena vicina horizon, correlated with the strata immediately below the Brannon siliceous limestone, in the Trenton of Central Kentucky. About 20 feet above the level of the Ohio River. Magnified 5 diameters.

Fig. 3. Thresherodiscus ramosa, Gen. et sp. nov. The floor plates are exposed along most parts of rays Nos. 1, 2, and 3. (See text figure of ray system, page V.) Lateral covering plates are seen along the upper side of the left primary ray, on the left side of ray No. 1, on the upper side of ray No. 4, and on the left side of ray No. 5. The central or median covering plates are present on various branches of rays Nos. 4 and 5, but are not distinguishable in the figure. The large central interambulacral plates are surrounded by a series of much smaller interambulacral plates which border upon the rays. From the Kirkfield or Curdsville member of the Trenton, along the railroad at the northeastern edge of Goat Island, northeast of Little Current, the chief village on Manitoulin Island, in Lake Huron. Magnified 5.7 diameters. Specimen No. 8446 in the collections of the Geological Survey of Canada, in the Victoria Memorial Museum, at Ottawa, Canada.

Fig. 4. Agelacrinus faberi, Miller. Resting on Hebertella alveata, Foerste. The granulated surface seen on various plates is regarded as due to a coating of some Dermatostroma. Near the central part of the figure two floor plates are shown at a point indicated by a tiny white arrow. Type, forming No. 8821 in the Faber Collection at Chicago University. Probably from the Whitewater member of the Richmond, immediately above the typical Saluda, at the exposure on the road side half way between Versailles and Osgood, along the road leading northward from the northeastern corner of the town square, at Versailles, Indiana. Magnified 4.5 diameters.



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2 A

2 B

3

4

PLATE IV

Fig. 1. Agelacrinus holbrooki, James. Showing the interambulacral plates between rays Nos. 1 and 2. Specimen No. 1004, in the James Collection at Chicago University Labelled as coming from near Lebanon, Ohio, and cited by John M. Nickles from the Corryville member of the Maysville formation.

Fig. 2. Streptaster septembrachiatus, Miller and Dyer. Under surface of upper or oral side of theca, showing the substomial chamber with the deep cavity or aperture at its posterior margin, and the inclined surface at the left of this margin. The floor plates are shown along the narrow bases of all the rays, and very much fore-shortened covering plates are seen along the side of the rays. Along the right margin of the figure some of the plates belonging to the inner band of the peripheral ring are nearly horizontal. From the Elkhorn member of the Richmond, six and a half miles west of the courthouse at Dayton, a sixth of a mile north of the Eaton pike, and about the same distance west of the Union road which leads northward to Trotwood, Ohio.

Fig. 3. Streptaster reversata, sp. nov. Fragment showing posterior half of theca, including nearly all of rays 1 and 5, with the intermediate posterior or anal interambulacral area; the latter shows the mosaic of small polygonal interambulacral plates; and the anal pyramid. Small interambulacral plates are shown also between ray No. 1 and the distal half of ray No. 2; also on the left of ray No. 2, as far up as the tip of ray No. 3. The upper edges of the large plates forming the inner band of the peripheral ring are well exposed, but only a part of the marginal plates of this ring are seen at several points. West of tressel 51, about two miles west of Million, in Madison County, Kentucky, west of Richmond. Horizon not definitely known but regarded as middle Eden Magnified 4.4 diameters.

Fig. 4. Vallatotheca manitoulini, Gen. et sp. nov. *A*, Lateral view; *B*, viewed from above. Genotype, differing from the congeneric Stenotheca unguiformis, Ulrich, in its much larger size and the greater curvature of the beak. The concentric markings are not due to transverse folds, but are successive lamellose outgrowths of the shell, striated only on their api al sides. From the Cape Smyth or Waynesville member of the Richmond, at the Clay Cliffs, on the eastern side of Cape Smyth, three miles north of Wekwemikongsing, on the eastern shore of Manitoulin Island. Specimen No. 8448, in the collections of the Geological Survey of Canada, in Victoria Memorial Museum, at Ottawa, Canada.

Fig. 5. Rhytimya kagawongensis, sp. nov. Mesial sulcus faint o obsolete. Concentric lines not more prominent anteriorly. Radiate lines, 7 to 10 in a width of 3 mm. on the posterior parts of the shell, increasing to 12 and more in same width anteriorly; consisting of discrete granules, enlarging in size posteriorly, where 6 may occur in a length of 1 mm. Characterized by its even and comparatively strong convexity, the umbonal ridge being only slightly defined at the beak, merging into the general convexity of the shell. Along the road from Kagawong to Gore Bay, several hundred yards before reaching the margin of the outcrop of the Cataract limestone, about two miles southwest of Kagawong, on Manitoulin Island. Specimen No. 8449, in the collections of the Geological Survey of Canada, in the Victoria Memorial Museum, at Ottawa, Canada.

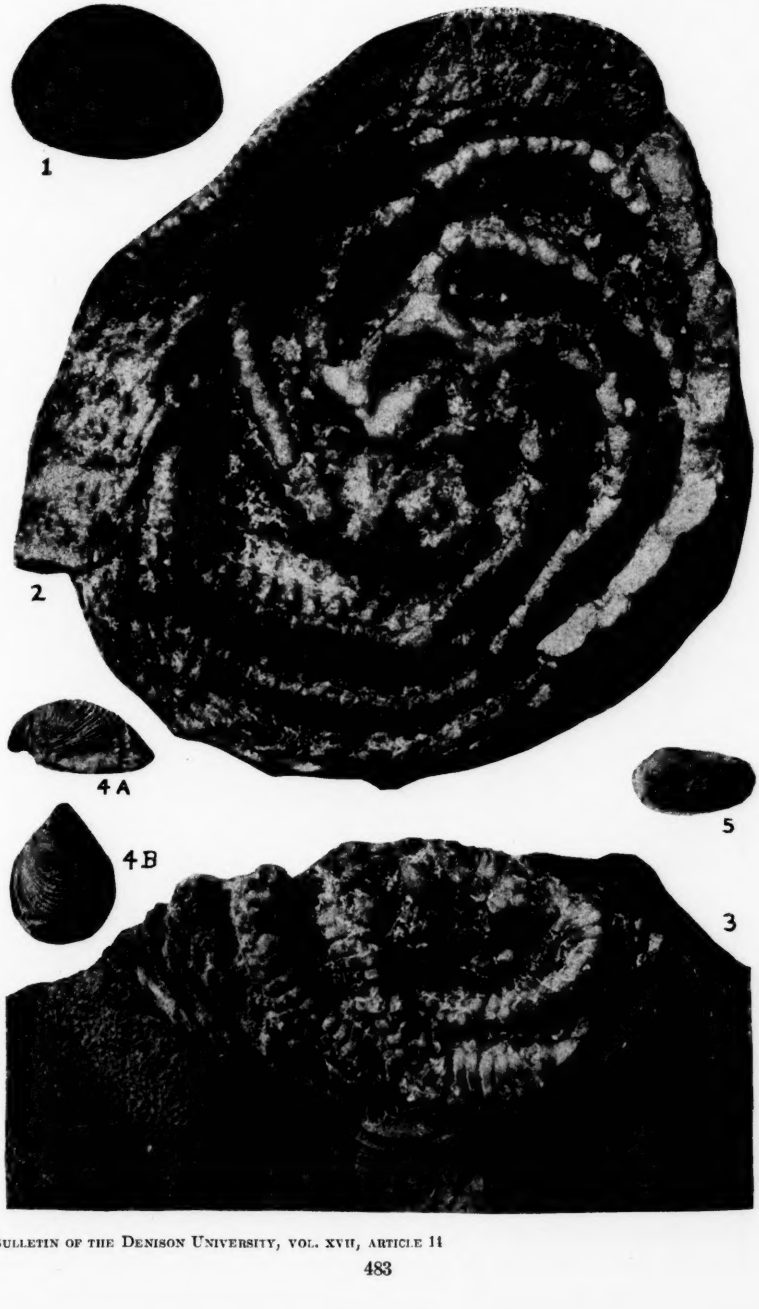

1
2
4 A
5
4 B
3

PLATE V

Fig. 1. Lepadocystis moorei, Meek. *A*, anterior view, exposing plate 15 and the anterior subvective food groove; also pectinirhombs 14–15, and 10–15. *B*, posterior view, showing pectinirhomb 11–17 on left side, pectinirhomb 12–18 near median line, and anal pyramid on right side of figure. Also right and left posterior subvective food grooves, with all of the distal floor plates dropped off in case of the right ambulacrum, and all but the terminal one of the distal floor plates gone in case of the left ambulacrum, in both cases leaving flattened surfaces, indicating the paths of the ambulacra. *C*, Left side of specimen *A*, broken at the base; with pectinirhombs 1–5, and 11–17; also the left anterior and left posterior branches of the subvective system. *D*, View of specimen *B*, from above, showing the subvective system, with the anterior branch directed toward the top of the figure. Along the lower margin of this figure the position of pectinirhombs 11–17, and 12–18, and location of the anal pyramid are indicated, indistinctly, in the shadows. Specimens No. 9961, in the Faber Collection at Chicago University. Figures *A* and *C* are prepared from the specimen lettered *A*; and figures *B* and *D*, from the specimen lettered *B*. From the Whitewater division of the Richmond, at Richmond, Indiana. Figures *A*, *G*, magnified 5.3 diameters. Figures *C*, *D*, magnified 4.7 diameters.

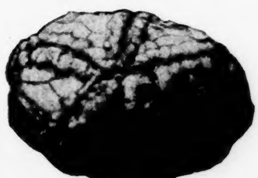
Fig. 2. Brockocystis tecumsethi, Billings. Genotype, and neotype of the species. *A*, View of top or oral end of specimen, but with anterior groove of subvective system directed toward the right. The large cavity on the right indicates the location of that part of the pectinirhomb 10–15 which is found on the nearly hemispherical plate 10. The cavity adjoining the lower left hand margin of the latter, in the figure, is the remainder of the pectinirhomb, with most of the stereom folds weathered out, and is located on plate 15. The cavity just beneath is the upper right hand side of that part of pectinirhomb which is located on plate 15. The longitudinal cavity on the left side of the figure is bordered on the left by the remains of the stereom folds on plate 12. The distal floor plates of all branches of the subvective system, excepting the right posterior branch, are missing and have left flattened areas on the theca. Traces of the hydropore and gonopore apparently present on the left of the center of the subvective system. *B*, posterior view; the large cavity locates pectinirhomb 12–18. The absence of the pectinirhomb on plates 11–17, immediately on the left of this cavity, is well shown. Pectinirhomb 1–5 is seen at the lower left hand margin of the figure. The anal area lies in the most deeply indented part of the outline on the right hand margin of the figure. *C*, View of right anterior side of specimen. The large cavity on the left side of the figure locates the anal area. Pectinirhombs 14–15, and 10–15 clearly indicated; also the flattened surfaces on the theca left by the dropping off of the floor plates from the distal ends of the branches of the subvective system. From the top of the Cataract limestone, on the road from Gore Bay to Kagawong, at the first wet weather stream crossing east of Ice Lake, on Manitoulin Island, in Lake Huron, *A*, Magnified 4.7 diameters; *B*, *C*, magnified 3 diameters. Specimen No. 847 in the collections of the Geological Survey of Canada, in the Victoria Memorial Museum, at Ottawa, Canada.

1 A

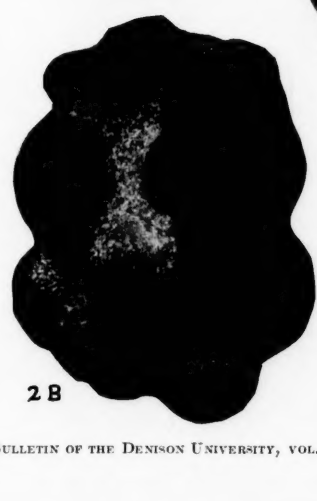
2 A

1 B

1 C



1 D



2 B

2 C

PLATE VI

Fig. 1. Agelacrinus *austini*, Foerste. *A*, specimen showing peripheral ring, with outer zone of small marginal plates, and inner band of larger plates. The anal pyramid is on the right, a short distance above the horizontal diameter. Ray 5 is directed upward and toward the right. Ray 4 is turned toward the left. The terminal part of ray 3 is well preserved. The long median or central covering plates are well shown in the specimen but can not be distinguished in the figure. *B*, lower side of upper part of the theca, showing the substomial chamber. The anterior outline, formed by the modified proximal floor plates of rays 2, 3 and 4, is well preserved. The outer ends of the proximal floor plates of rays 1 and 5 are in position, but the inner ends, toward the median line of the specimen, have been swung forward, partly closing the substomial ravity, evidently owing to displacement after death. The floor plates of rays 2 and 3, and a part of those of ray 1, are well preserved. They consist of a single series in the case of each ray, and no glimpse of the basal extensions of the lateral covering plates may be seen. *C*, one of three specimens resting upon the flattened surface of a bryozoan which had been very much worn before the attachment of the specimens. Anal area on the left. The curvature of the rays is less than in fig. 1*a*. Interambulacral plates more numerous in the distal part of the posterior area than in any of the other interambulacral areas. All figures magnified 4.2 diameters. Specimens in the collection of Dr. G. M. Austin; from the Drepanella richardsoni horizon, at the top of the Whitewater member of the Richmond, on Dutch creek, south of the Oakland pike, four and a half miles northwest of Wilmington, Ohio.

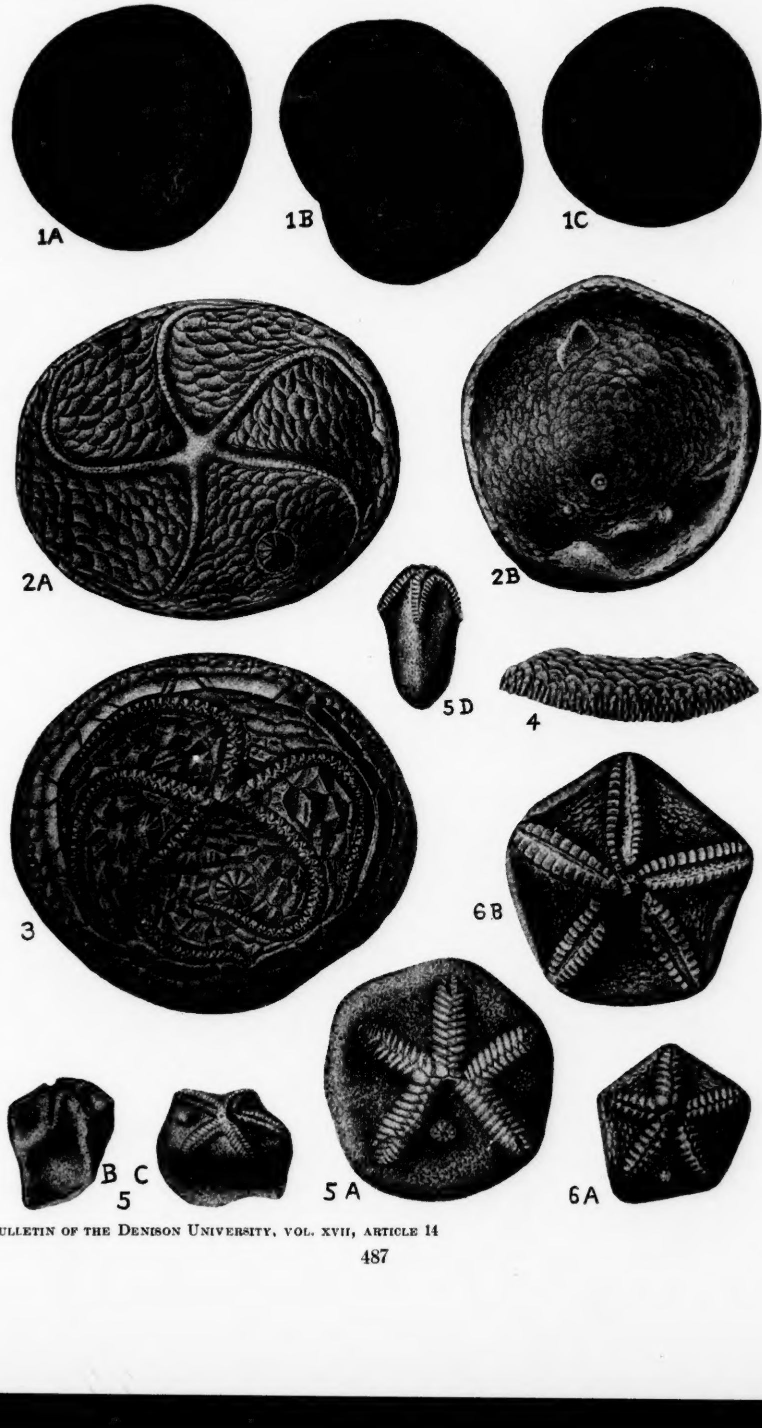
Fig. 2. Lepidodiscus alleganius, Clarke. *A*, oral aspect of a mature individual, showing the extremely narrow, undulating, whiplash rays, all solar; the small cover plates; the anal pyramid composed of 10 triangular plates; and the absence of specially differentiated marginal plates. Magnified 1.5 diameters. Chemung sandstone. Loose at Alfred, New York. *B*, Aboral aspect of a large individual, showing the depressed surface with imbricating plates directed centrifugally and the projecting margin of coarser plates. Natural size. Chemung sandstone. Loose at Belvidere, New York. Figures copied from Bull. 49, N. Y. State Museum, 1901, pl. 10, figs. 4, 2. Plastotypes Nos. 4285-4 and 2 respectively, in the New York State Museum, at Albany, N. Y.

Fig. 3. Agelacrinites hamiltonensis, Vanuxem. Drawing made from guttapercha replica of original, showing form and direction of rays, the large submarginal and small marginal plates, the sculptured surface of the interambulacral plates, and the anal pyramid. Magnified 2 diameters. Hamilton beds. West Hamilton, Madison county, New York. Part of figure 6, on pl. 10 of Bull. 49, N. Y. State Museum, 1901. Plastotype No. 4000-1, New York State Museum.

Fig. 4. Streptaster vorticellatus, Hall. A portion of the peripheral ring of the type, showing the relative size and arrangement of the plates. Magnified 5 diameters. Maysville formation, Cincinnati, Ohio. Type, No. 1192, in the American Museum of Natural History, in New York City. Copy of fig. 12 on pl. 6, of the 24th Annual Report of the N. Y. State Museum, 1872.

Fig. 5. Cystaster granulatus, Hall. *A*, view of the summit of a specimen, enlarged 4 diameters, showing the covering plates of the rays and the anal pyramid. *B*, lateral view of a specimen, with the covering plates of the rays missing; only lower range of plates of anal pyramid present, lower margin shows cicatrix of attachment to some foreign body. *C*, oblique summit view of another individual, with covering plates present only on the two nearer rays. *B* and *C*, enlarged 2.5 diameters. *D*, lateral view of a specimen with a more elongate body, pointed below, showing no evidence of having been attached; covering plates absent. Enlarged 3 diameters. The originals of figures *B*, *C*, and *D* are numbered 40 in the Dyer collection, at Harvard University. The original of fig. A should be in the same collection but was not noticed by me. Fairmount member of the Maysville formation, at Cincinnati, Ohio. Copied from figs. 1, 2, 3, 4, on pl. 6, in the 24th Ann. Rept. N. Y. State Museum.

Fig. 6. Hemicystites stellatus, Hall. *A*, a small individual, enlarged 6 diameters. Rays with covering plates, about 7 or 8 in each range. With distinct imbricating plates and anal pyramid. On Rafinesquina alternata. Type, No. 1191-1, in the American Museum of Natural History, in New York City. *B*, a summit view of a larger individual, enlarged 4 diameters. Covering plates missing. Interambulacral plates in the upper left-hand area, distinctly imbricating. Maysville formation. No. 1193 in Dyer collection at Harvard University.


1A
1B
1C
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2B
5D
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6B
B C
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